Fall 1983

Diatoms and Magnetic Anisotropy as Means of Distinguishing Glacial Till from Glaciomarine Drift

Robert Crandall
Western Washington University

DIATOMS AND MAGNETIC ANISOTROPY AS MEANS

OF DISTINGUISHING GLACIAL TILL FROM GLACIOMARINE DRIFT

A Thesis

Presented to

The Faculty of

WESTERN WASHINGTON UNIVERSITY

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

by

Robert Crandall

FALL 1983

~~May 1979~~

MASTER'S THESIS

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Western Washington University, I grant to Western Washington University the non-exclusive royalty-free right to archive, reproduce, distribute, and display the thesis in any and all forms, including electronic format, via any digital library mechanisms maintained by WWU.

I represent and warrant this is my original work and does not infringe or violate any rights of others. I warrant that I have obtained written permissions from the owner of any third party copyrighted material included in these files.

I acknowledge that I retain ownership rights to the copyright of this work, including but not limited to the right to use all or part of this work in future works, such as articles or books.

Library users are granted permission for individual, research and non-commercial reproduction of this work for educational purposes only. Any further digital posting of this document requires specific permission from the author.

Any copying or publication of this thesis for commercial purposes, or for financial gain, is not allowed without my written permission.

Name: Robert P. Crandall

Signature: [illegible]

Date: 5/16/2018

DIATOMS AND MAGNETIC ANISOTROPY AS MEANS

OF DISTINGUISHING GLACIAL TILL FROM GLACIOMARINE DRIFT

by

Robert Crandall

Accepted in Partial Completion

of the Requirements for the Degree

Master of Science

Dean of Graduate School

Advisory Committee

Chairman

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The author would like to thank Dr. Fred Pessel, U.S. Geological Survey, Seattle, Washington, for partial funding of the project; Paul Heller, U.S. Geological Survey, Menlo Park, California, Bob Siegfried, U.S. Forest Service, Olympia, Washington, and John Spasari, Shannon and Wilson, Inc., Seattle, Washington, for help in collecting samples; Dr. Myrl Beck and Dr. Chris Suczek, Western Washington University, Dr. V. Standish Mallory, University of Washington, for suggestions, invaluable discussions, and criticisms of the text; Dr. Don Easterbrook, Western Washington University, for support in all phases of the project and an editorial effort worthy of recognition; my parents for much moral support.

ABSTRACT

Fossil diatom occurrence and anistropy of magnetic susceptibility are evaluated for their usefulness in differentiating glaciomarine drift from till.

Fossil diatoms in Everson glaciomarine drift occur abundantly enough to be of paleoenvironmental significance only in association with _in situ_ _Serpula vermicularia_ (Linne). Diatoms are generally a poor discriminator between till and glaciomarine drift. Paleoecological data suggest that, berg ice in marine water was the dominant agent of transportation for clastic particles in Everson glaciomarine drift.

Anisotropy of magnetic susceptibility investigations generated a characteristic magnetic signature for each diamicton, demonstrating intrinsic differences in the petrofabrics of the two sediment types.

INTRODUCTION

Glaciomarine drift and till are diamictons which represent two facies of glacial drift. Glacial drift "embraces all rock material in transport by glacial ice, and all deposits made by glacial ice, all deposits predominantly of glacial origin, made in the sea or in bodies of glacial meltwater, whether rafted in by icebergs or transported in the water itself" (Flint, 1957). The term till is used in this thesis to refer to all diamictons deposited directly on land by glacial ice. Glaciomarine drift is deposited in marine waters directly by ablation of floating ice. Till and glaciomarine drift are frequently similar in appearance and can be difficult to differentiate. (Armstrong and Brown, 1954; Easterbrook, 1963).

The primary differences between till and glaciomarine drift in the Puget Lowland are; (1) glaciomarine deposits have lower bulk densities and higher void ratios (Easterbrook, 1964); (2) *in situ* marine fossils occur in the glaciomarine deposits (Armstrong and Brown, 1954; Easterbrook, 1963); (3) glaciomarine deposits sometimes contain a larger proportion of fine particles (Easterbrook, 1963). The high degree of variability in particle size distribution in these sediments sometimes makes these criteria for differentiation uncertain in areas that lack fossils.

The purposes of this study are: (1) to examine two methods, fossil diatom analysis and anisotropy of magnetic susceptibility, for distinguishing glaciomarine drift from till, and (2) to study the paleoenvironmental significance of Everson glaciomarine sediments in the northern Puget Lowland.

Everson glaciomarine drift (Easterbrook, 1963; Armstrong, et al., 1954) was examined for fossil diatoms to determine which species occur and what factors control their preservation. The goal of this investigation was to evaluate the usefulness of fossil diatoms in discriminating Everson glaciomarine drift from Vashon till and to integrate paleoecological data yielded by this investigation into the previously established model for glaciomarine sedimentation in the Pleistocene of the northern Puget Lowland (Easterbrook, 1963; Armstrong, et al., 1954).

Diatoms are the primary source of food in marine environments (Patrick and Reimer, 1966) and as such are more frequently encountered in marine waters than other invertebrates. The ubiquitous occurrence of these organisms in marine environs has lead to their more common representation in Everson glaciomarine sediments than other fossil groups. A suite of marine diatom species characteristic of the Everson Interstade was delineated.

The second method employed in this study is a fully tested, indirect estimation of petrofabrics by analysis of rod-shaped, multidomain magnetic grain alignment, anisotropy of magnetic susceptibility. Degree of orientation of inequant magnetic grains that are too large to be affected by the geomagnetic couple has long been recognized as a function of shear in the depositional environment (Fuller, 1964; Krumbein and Sloss, 1963). Most subglacial till is deposited in a water-saturated, high shear environment (Easterbrook, verbal communication), and as such, commonly contains a well defined petrofabric that is easily detected through this technique (Gravenor and Stupavsky, 1975). Glaciomarine drift is essentially a suspension deposit (Armstrong and Brown, 1954; Easterbrook, 1963) in marine waters and characteristically has a less well defined alignment of constituent elongate particles than till. This line of investigation was chosen because it dealt with an intrinsic property of each sediment type and, unlike paleontologic techniques, was used to compare unfossiliferous sediments.

FOSSIL DIATOM INVESTIGATIONS

SAMPLING

One hundred four samples were collected from 14 Everson Interstade glaciomarine localities in the northern Puget Lowland (Figure 1). Localities were restricted to horizons which had demonstratable lateral contiguity with known Everson glaciomarine localities.

Standard methods for the preparation of diatom samples, as described by Schrader (1974), and Brady (1977), were found to be largely ineffective for Everson glaciomarine sediments because most samples had very low concentrations of diatom frustrules per gram of sediment. Standard preparation techniques developed for normal marine sediments generally employ a sample size of 1-3 mls, but this volume is not adequate for areas of low diatom productivity or high sedimentation (Brady, 1977). For the purposes of this study, a sample size of approximately 150 mls was found to be appropriate as this volume represents the largest amount of sediment which can be analyzed at one time using the following technique.

Processing Technique

The unconsolidated nature of the Everson sediments simplifies sample preparation. Samples were immersed in a solution of less than 10% hydrogen peroxide and boiled for approximately one hour to disperse the sample and clean the diatom frustrules. After boiling, the sample was stirred and its constituent particles allowed to settle 10 minutes per cubic centimeter of water (Brady, 1977), to allow fractionization of the particles on the basis of settling velocity.

Figure 1. Fossil diatom sampling locations, Everson glaciomarine drift

The large sample size necessitated the use of a 20 μ screen to separate the diatoms from the clay-sized particles. The fine-grained fraction was decanted and flushed with distilled water through the screen. Twenty μ was the smallest size screen found suitable for this purpose. The screening was conducted as quickly as possible to retain as much of the 20μ - 5μ fraction as possible.

The flushed fraction was then decanted and dispersed in approximately 30 mls. of distilled water. Slides were prepared by placing several drops of this solution on a slide and evaporating the water. The slide was then examined under a microscope to determine if the sample contained diatoms. Four slides mounted in hydrax or lakeside cement were then made from horizons showing optimal preservation. Samples found to be initially barren were treated with zinc bromide in the manner described by Brady, (1977). The addition of zinc bromide to the sample raised the density of the water to 2.5 gm/cm^3, allowing diatom frustrules of a density of 2.0-2.1 gm/cm^3 (Patrick and Reimer, 1966) to be separated from the more dense minerals by decanting. If this procedure produced no frustrules, the horizon was considered barren.

Quantitative Studies

A total of 200 diatoms, (50 per slide) were counted from each horizon found to be abundantly fosssiliferous. The slides were traversed using a mechanical stage. Fragments which represented over 1/2 of a frustrule were counted (Abbott, 1972; Barron, 1973).

After the statistical sample had been taken, the slides were scanned again to verify that all statistically important species were represented in the count (Barron, 1973).

Samples treated with zinc bromide yielded an incomplete sample of the flora that precluded quantitative analysis. This settling technique did not completely remove all diatom frustrules from a sample, but made possible the finding of whole frustrules in highly fragmented zones. Although the whole flora was not obtained, significant paleoecological data was obtainable through this procedure (Brady, 1977).

The processing techniques used in this study induced a bias toward larger frustrules. Screening of the sample removed some of the smaller-than-20 μ frustrules and fragments, although care was taken to wash the sediment as little as possible. The loss of diatoms using this method was difficult to assess and made this method of preparation justifiable only when standard methods are ineffective. The vast majority of diatoms are larger than 20 μ in at least one dimension and the bias toward larger forms induced by this procedure is minimal. This assumption was verified by examination of the slides, which revealed that a majority of the particulate matter was less than 20 μ in diameter.

Diatom Preservation in Everson Sediments

Glaciomarine Drift

Most glaciomarine sediments sampled in this study were taken from fossiliferous localities in order to insure that all sediment collected was in fact Everson glaciomarine drift. Diatom preservation was found to be optimal in localities that contained in situ marine invertebrate fossils, particularly the annelid Serpula vermicularis (Linne). These localities were the only ones which yielded a sufficiently well preserved flora to be of paleoecological significance beyond establishing that the environment was marine.

Approximately 90% of the glaciomarine sediment sampled containing only shell fragments or lacking macrofossils were barren. The limited occurrence of diatoms in these sediments indicates that Everson glaciomarine deposits cannot invariably be recognized on the basis of diatom evidence. The distribution of fossil diatoms in horizons lacking in situ invertebrate macrofossils appears to be random; thus, intensive sampling of a questionable horizon may produce fossil evidence. Glaciomarine samples that contain no diatoms may contain rather poorly preserved sponge spicules and pollen.

The most practical application of this technique is as a confirming check of a horizon suspected from other evidence to be glaciomarine drift.

The paucity of diatoms in glaciomarine drift of the Everson Interstade is thought to be due to preservational factors rather than depositional conditions. This contention is supported by the following evidence;

1) Species occurring in the glaciomarine sediments are primarily coarse oceanic species, resistant to dissolution, and most likely to be preserved intact in invertebrate fecal matter (Krebs, 1977; Lisitin, 1971), as shown in Figures 2 and 3.

2) The primary productivity of the Puget Lowland during the Everson Interstade was probably very high because; (a) productivity of diatoms proceeded at higher rates during late Pleistocene interstades than during the Holocene (Jouse, 1971; Jouse, et al., 1971) and, (b) the Puget Lowland today is one of the most productive regions of the world (Lisitin, 1971; Patrick and Reimer, 1966).

3) Diatoms are susceptible to leaching by groundwater (Brady, 1977; Heath, 1974).

4) Everson sediments in the study area were emergent soon after deposition (Easterbrook, 1963).

5) Iron oxides are frequently seen precipitated on diatom frustrules in the Everson sediments, as shown in Figure 4.

6) The distribution of diatoms in the Everson sediments indicates that only those encased in invertebrate fecal matter are preserved, as noted by Lisitin (1969) in the sediments of the Bering Sea.

The last factor explains the random occurrence of diatoms from localities that lack in situ marine forms. Presumably preservation at these sites is due either to winnowed fecal matter from macrofossil localities, or more probably, zoo plankton. The significance of these organisms in preserving diatoms in unfavorable conditions has long been recognized and is thoroughly discussed in Lisitin (1969), Schrader (1971), and Krebs (1977).

Paleoecological Data

Ninety eight percent of all stenothermal diatom species encountered in the Everson glaciomarine sediments belong to the north-boreal complex of Jouse, et al., (1969), Jouse, et al., (1971), and Jouse (1971) (See Appendix 1). The Puget Lowland during the Everson Interstade is thought to have been colder than at present, in view of the near absence of diatom species indicative of the sub-tropical diatom complex. There is also no evidence of diatom species associated exclusively with the arctoboreal diatom complex. These facts limit the range of temperatures assignable to the Puget Lowland during the Everson Interstade.

The marine waters of the Puget Lowland during the Everson Interstade were characterized by sub-arctic temperatures. Five degrees centigrade is an appropriate estimate of a winter low isotherm from about 13,000 to 11,500 years B.P.. Radiocarbon dates are available for three of the sites that yielded sufficient numbers of diatoms to be of paleoenvironmental significance;

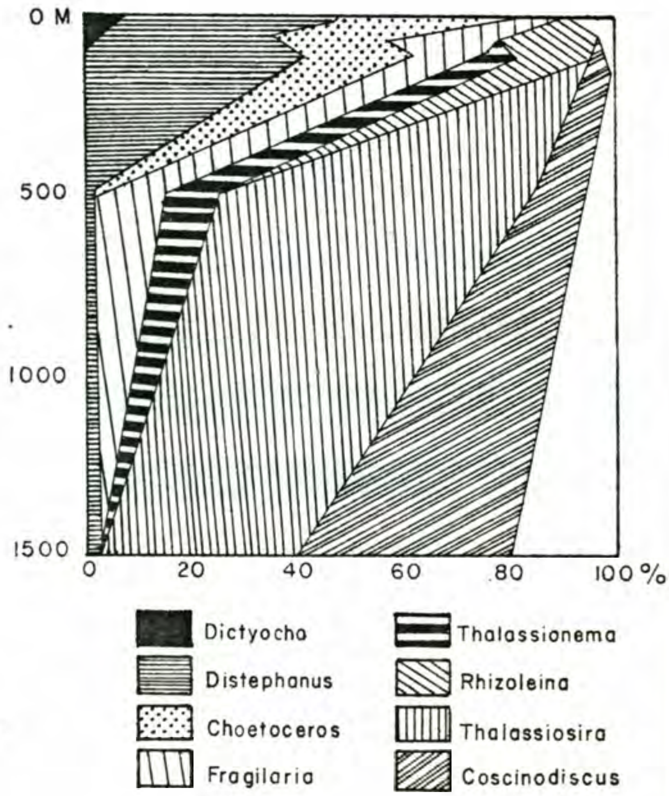


Figure 2. Changes of the quantity and specific composition of diatoms and silicoflagellates in suspended matter from 0 to 1,500 meters in the vicinity of Japan (Oshite) (Lisitin, 1971).

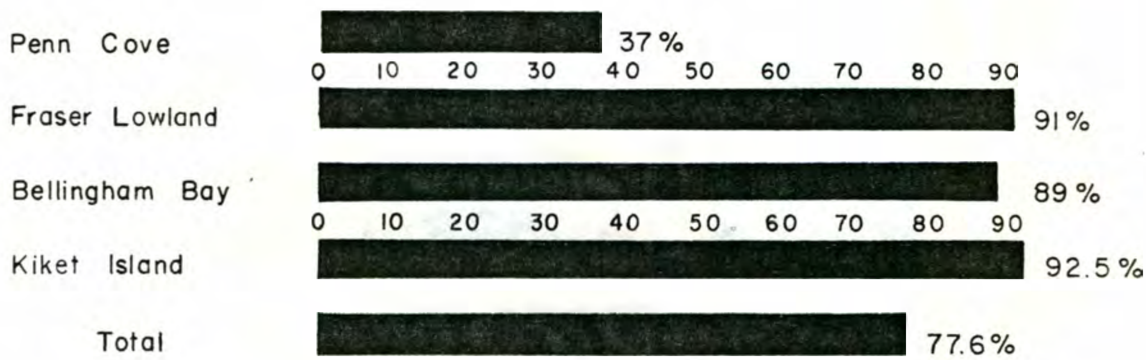


Figure 3. Percentage composition of Coscinodiscus and Thalassiosira frustules in diatom assemblages from Everson glaciomarine sample locations.

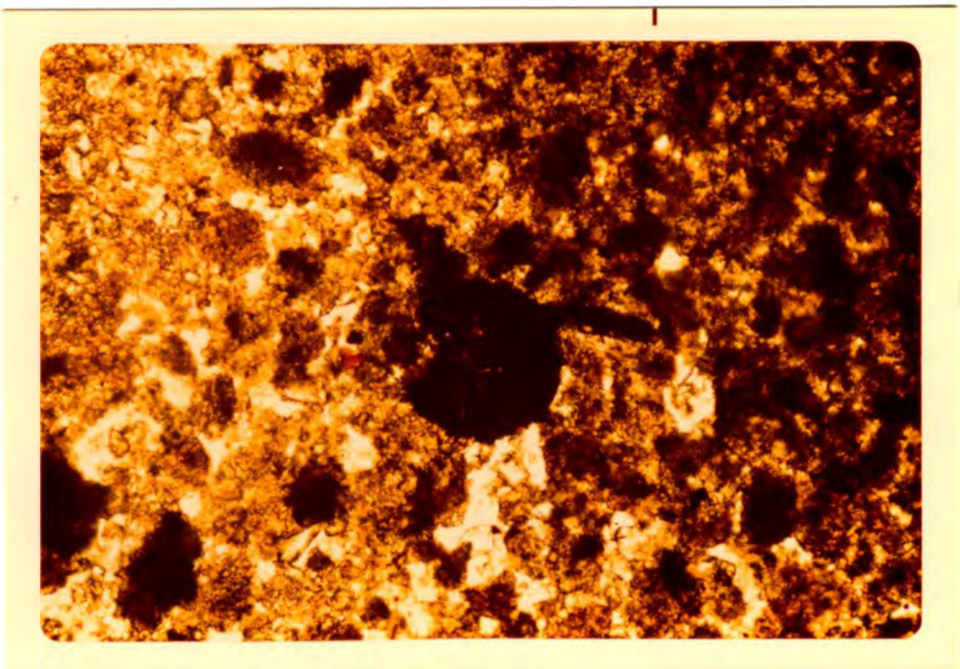


Figure 4. Coscinodiscus frustule with iron oxide precipitate.

Penn Cove, Whidbey Island, 13,010 ± 170 years B.P. (Easterbrook, 1966); Fraser Lowland, Highway 99A 4 km north of the U.S. border, 12,625 ± 450 years B.P. (Armstrong, 1960); and Bellingham Bay, 11,650 ± 350 years B.P. (Easterbrook, 1963). The Everson Interstade is thought to encompass approximately 2,500 years, from approximately 10,500 to 13,000 years B.P. (Easterbrook, 1963). The localities reported in this thesis represent the lower through middle part of the Everson Interstade.

The Penn Cove, Whidbey Island assemblage is shown in Table 1.

Table 1

Diatom species, percent composition, Penn Cove, Whidbey Island, 13,010 ± 170 years B.P..

Species	Percent Total
Campylodiscus thuretii Breb	41.0%
Coscinodiscus curvatulus Grunow	1.5%
C. marginatus	2.0%
C. occulus - iridus Ehrenberg	13.0%
Melrosira sp. Agarth	1.0%
Navicula distans W. Smith	1.0%
Nitzschia seriata Cleve	1.5%
Rhabdonema arcuatum Grunow	10.0%
R. minutum Kutzing	6.0%
Thalassiothrix longissima Cleve & Grunow	2.5%
Thalassiosira excentrica Cleve	16.0%
Thalassiosira sp. Cleve	4.5%

This assemblage is dominated by the diatom Campylodiscus thuretii Breb., indicative of littoral environments (Heurck, 1896). The dominance of this species is thought to exclude the possibility that this assemblage could have developed under shelf ice because photosynthesis in littoral zones is incompatible with shelf ice environments. The assemblage contains 42.5% stenothermal planktonic marine forms, implying near-normal marine salinities, unrestricted communication with the planktonic oceanic environment, and a winter-low isotherm of 5° centigrade.

Table 2

Diatom species, percent composition, Fraser Lowland, Canada, 12,625 ± 450 years B.P..

Species	Percent Total
Biddulphia auria (Lyngbye)	1.0%
Coscinodiscus curvatulus Grunow	31.0%
C. marginatus Ehrenberg	2.0%
C. occulus - iridus Ehrenberg	26.0%
Melrosira sp. Agarth	1.0%
Navicula distans W. Smith	1.0%
Nitzschia seriata Cleve	4.0%
Thalassiosira excentrica Cleve	24.0%
Thalassiosira sp. Cleve	9.0%
Surriella sp. Turpin	1.0%

The Fraser Lowland assemblage is composed of 83% temperature-specific planktonic oceanic forms, indicating unrestricted communication with the planktonic oceanic environment, near-normal marine salinities, and a winter-low isotherm of 5° centigrade. Foraminifera from this locality indicate deposition in shallow waters, perhaps less than 15 meters, with reduced salinities (Smith, 1970). The foraminifera are considered to be a more accurate indicator of paleosalinities in this instance, due to the pronounced tendency for coarse marine planktonic species of diatoms to dominate the fossil assemblages.

The Bellingham Bay assemblage is listed in Table 3.

Table 3

Diatom species, percent composition, Bellingham Bay, Washington, Kulshan glaciomarine drift, 11,650 ± 350 years B.P..

Species	Percent Total
Coscinodiscus curvatulus Grunow	16.5%
C. marginatus Ehrenberg	2.5%
C. occulus - iridus Ehrenberg	21.0%
Nitzschia seriata Cleve	3.5%
Rhabdonema arcuatum Grunow	3.0%
Rhabdonema sp. Kutzing	2.0%
Surriella sp. Turpin	.5%
Thalassiosira decipiens (Grunow)	9.0%
T. excentrica Cleve	33.0%
Thalassiosira sp. Cleve	7.0%
Thalassiothrix longissima Cleve & Grunow	2.0%

The Bellingham Bay locality contains 76% planktonic oceanic, temperature-specific forms indicating unrestricted communication with the planktonic oceanic environment, near-normal marine salinities, and a winter-low isotherm of 5° centigrade. Macrofossils from this locality have been shown to be indicative of a depth of deposition of approximately 30 meters or less

(Easterbrook, 1963; Mallory, et al., 1972).

The Kiket Island assemblace is listed in Table 4.

Table 4

Diatom species, percent composition, Kiket Island, Washington, Everson glaciomarine drift, no C^{14} date available.

Species	Percent Total
Biddulphia aurita (Lyngbye)	0.5%
B. roperiana Greville	0.5%
Coscinodiscus curvatulus Grunow	3.5%
C. occulus - iridus Ehrenberg	13.0%
Navicula distans W. Smith	0.5%
Rhabdonema arcuatum Grunow	5.0%
Thalassiosira excentrica Cleve	69.5%
Thalassiosira sp. Cleve	7.5%

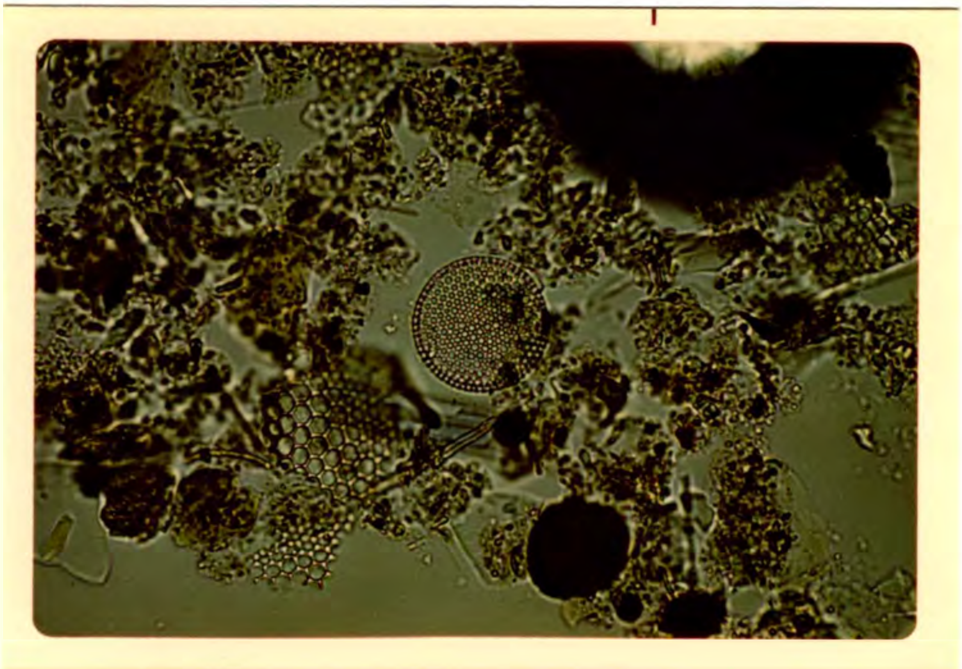
The Kiket Island locality assemblage contains 91.0% temperature-specific planktonic oceanic species indicating near-normal marine salinities, unrestricted communication with the oceanic planktonic environment and a winter-low isotherm of 5° centigrade.

The suite of diatom species indicative of Everson glaciomarine drift are shown in Figures 5 through 16. Other microfossils which commonly occur with diatoms in Everson glaciomarine drift using the sample preparation techniques previously described are shown in Figures 17 through 20.

Environment of Deposition

The data reported here indicate that sea water temperatures during the lower through middle part of the Everson Interstade in the northern Puget

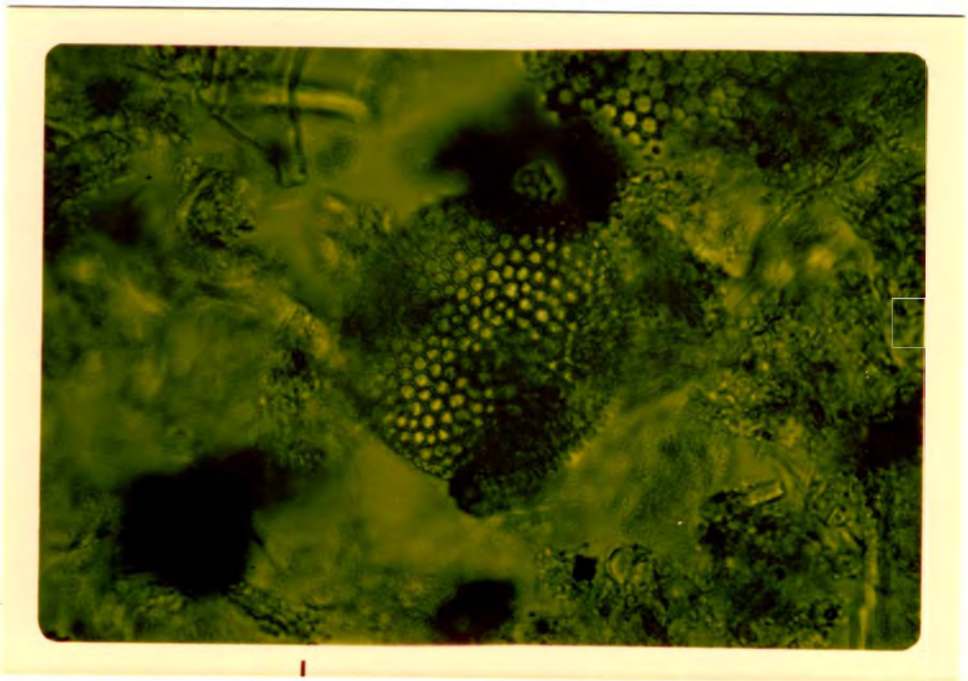
DIATOMS CHARACTERISTIC OF EVERSON GLACIOMARINE SEDIMENTS



25μ

Thalassiosira dicipiens (Grunow)

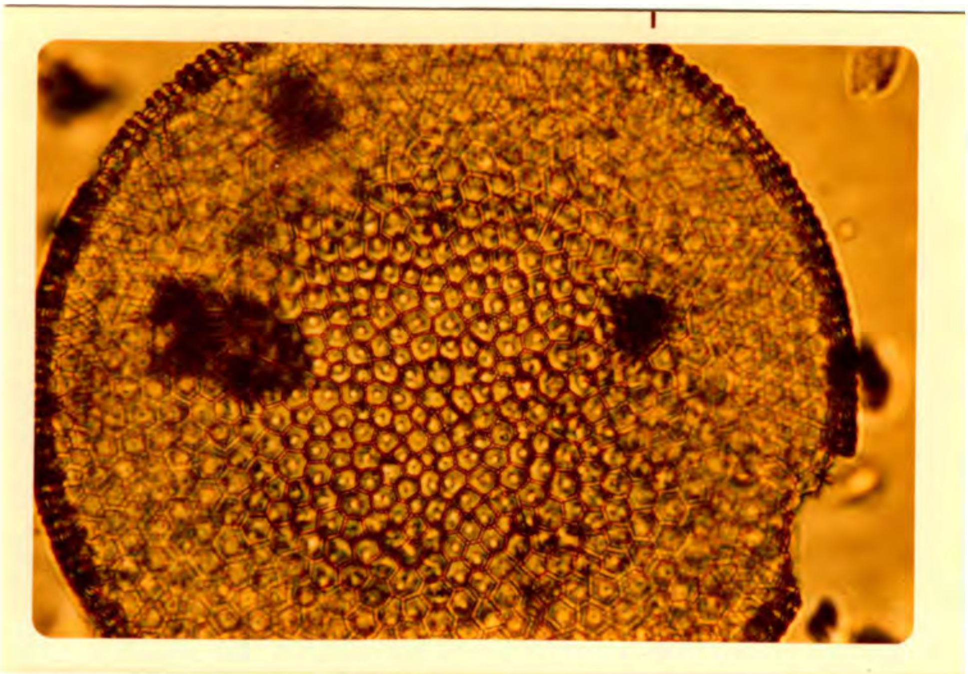
Figure 5



50μ

Thalassiosira excentrica Cleve

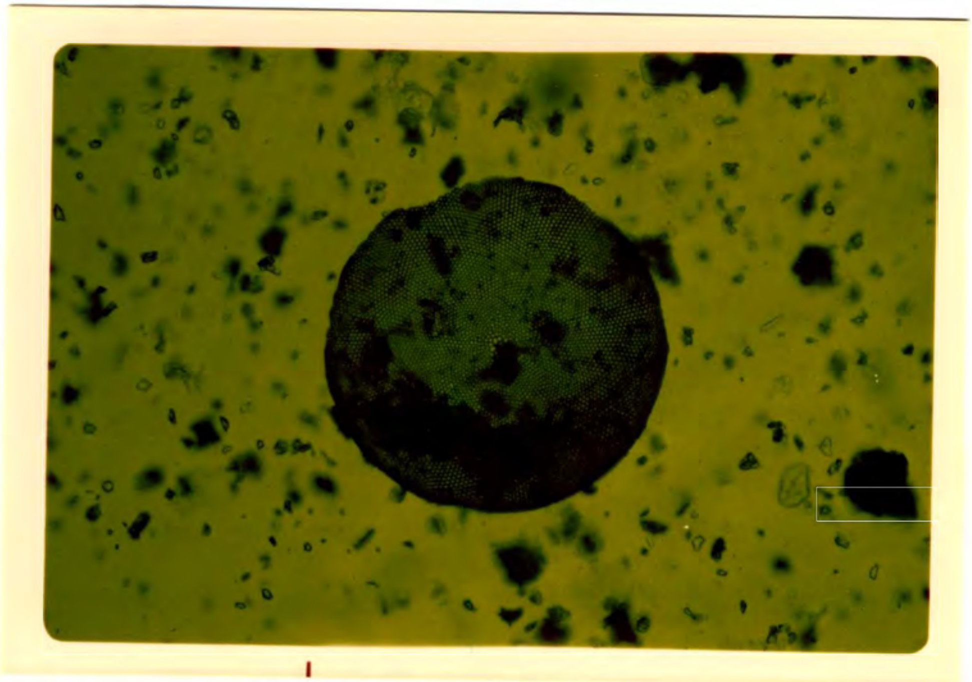
Figure 6



15 µ

Coscinodiscus marginatus Ehrenberg

Figure 7



25 µ

Coscinodiscus occulus-iridus Ehrenberg

Figure 8

25μ

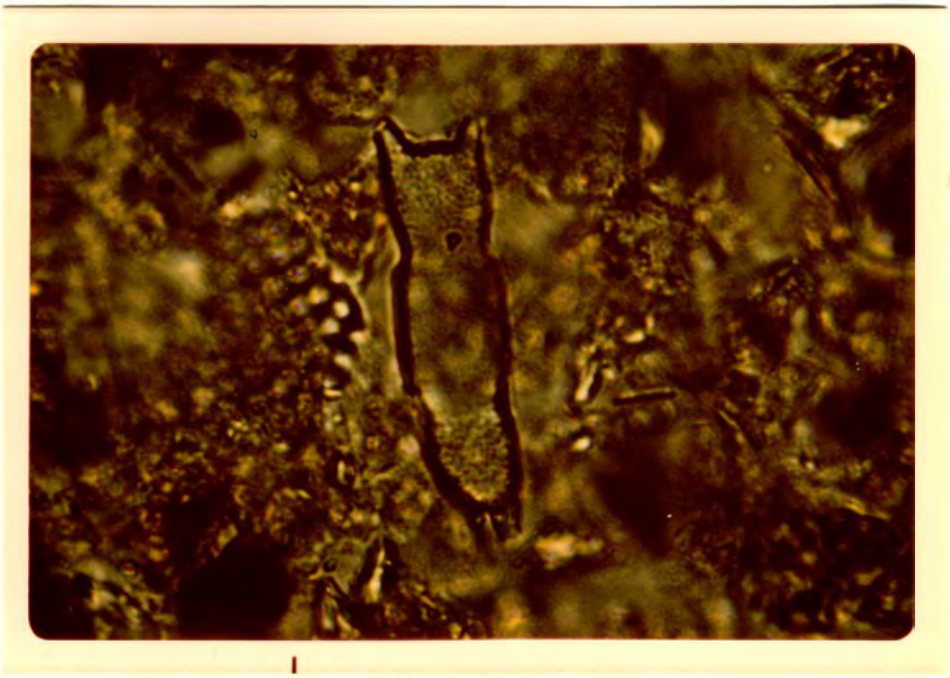
Coscinodiscus curvatulus Grunow

Figure 9

25μ

Campylodiscus thuretii Breb

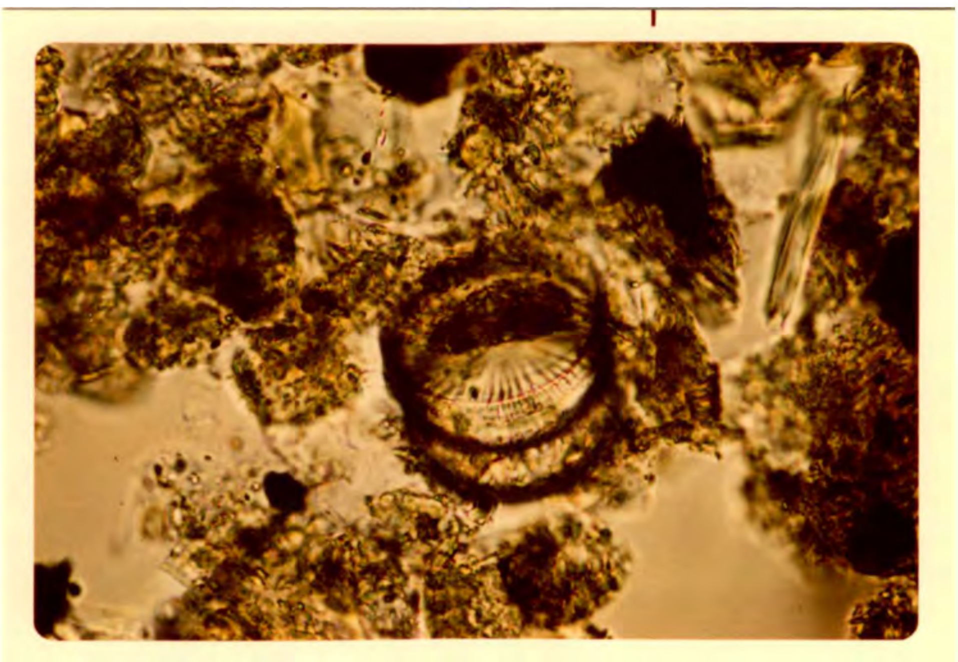
Figure 10



25μ

Biddulphia roperiana Greville

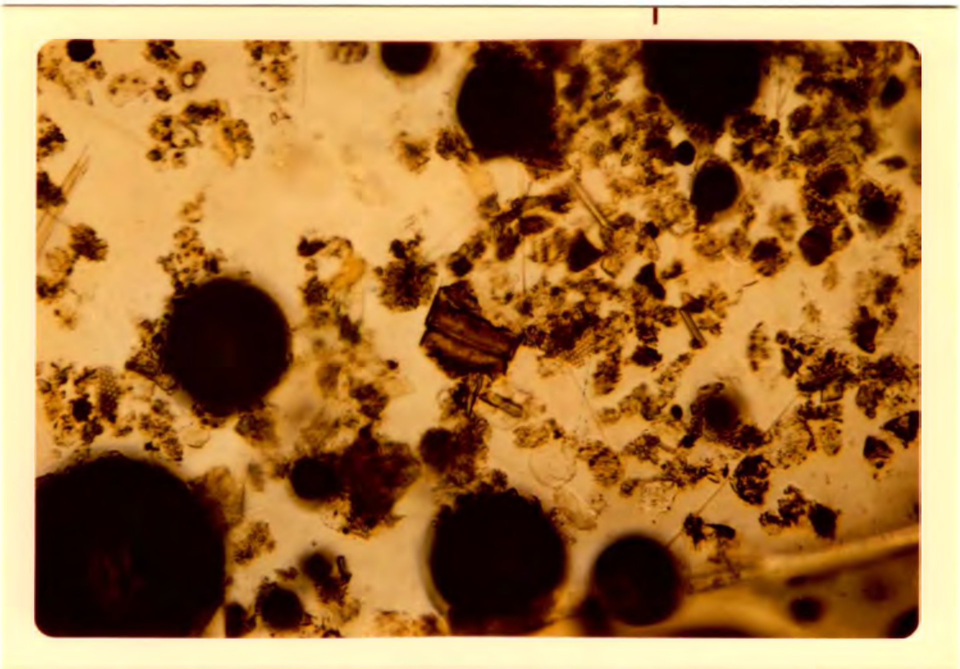
Figure 11



25μ

Thalassiosira sp. Cleve

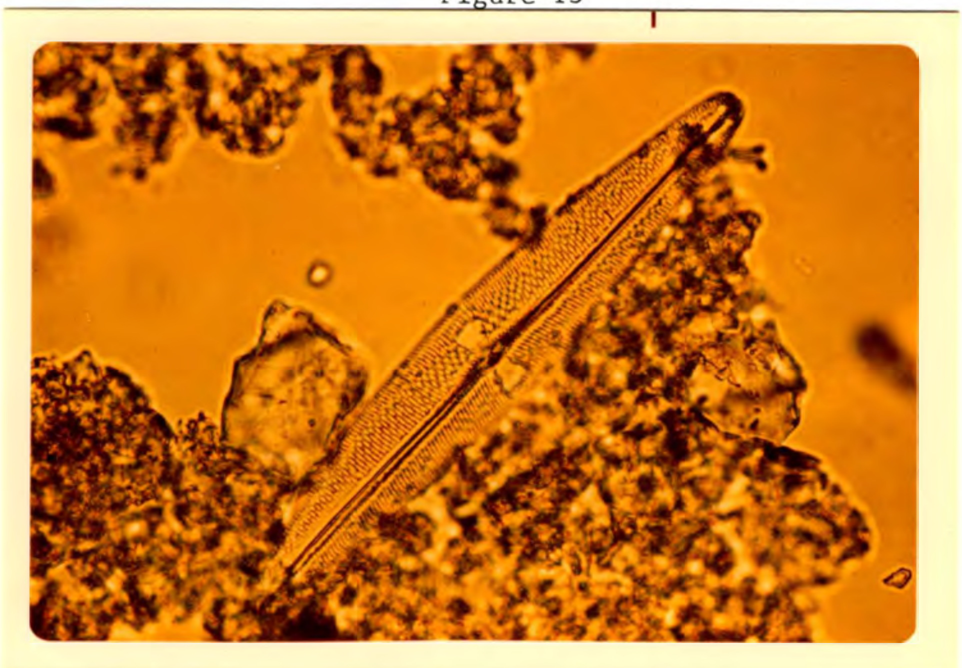
Figure 12



20μ

Biddulphia auria (Lyngbye)

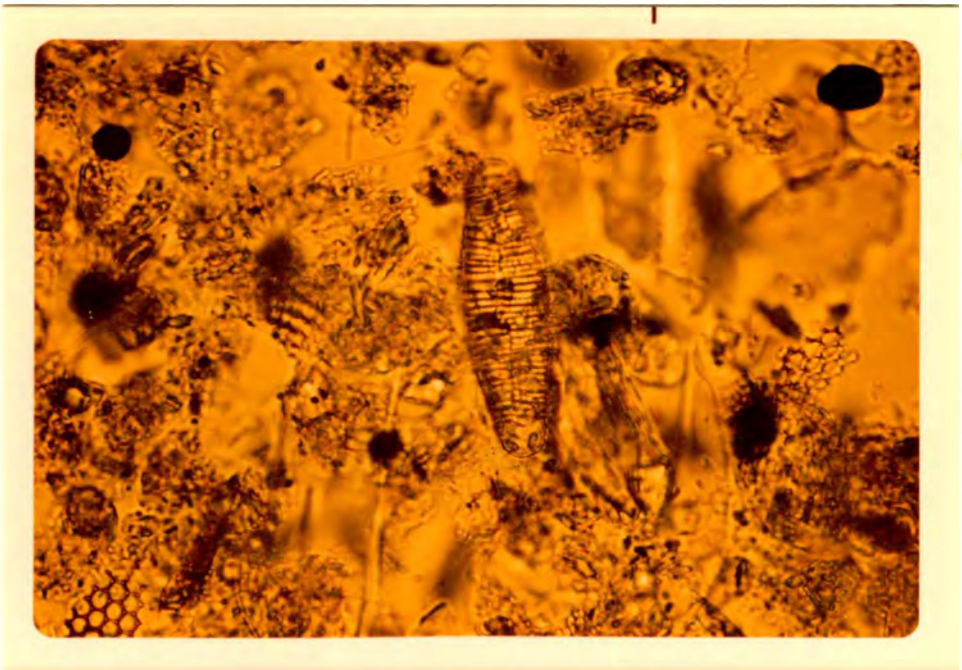
Figure 13



20μ

Navicula distans Smith

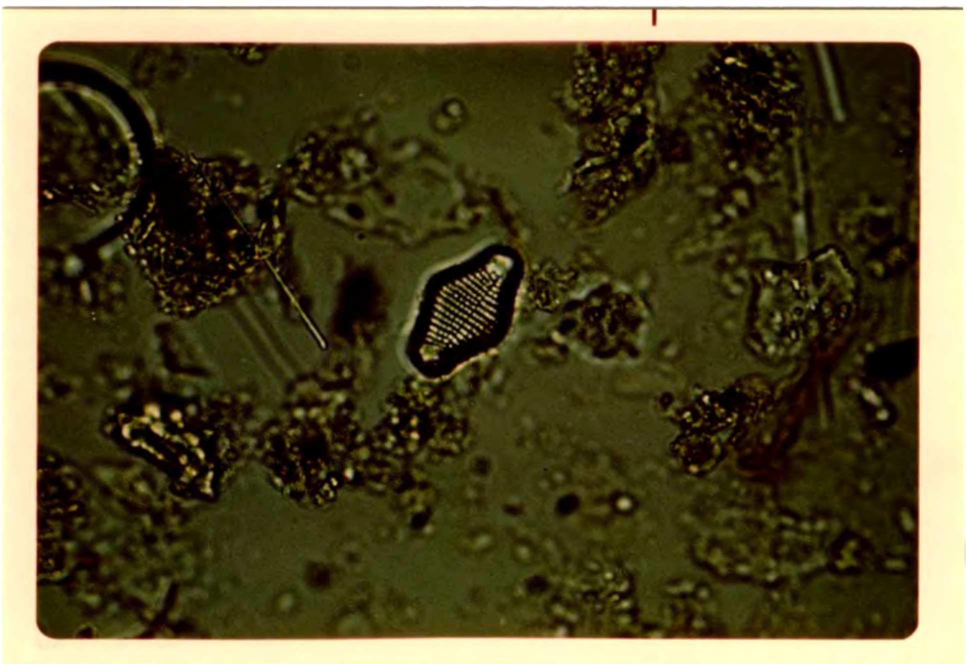
Figure 14



40µ

Rhabdonema arcuatum Grunow

Figure 15

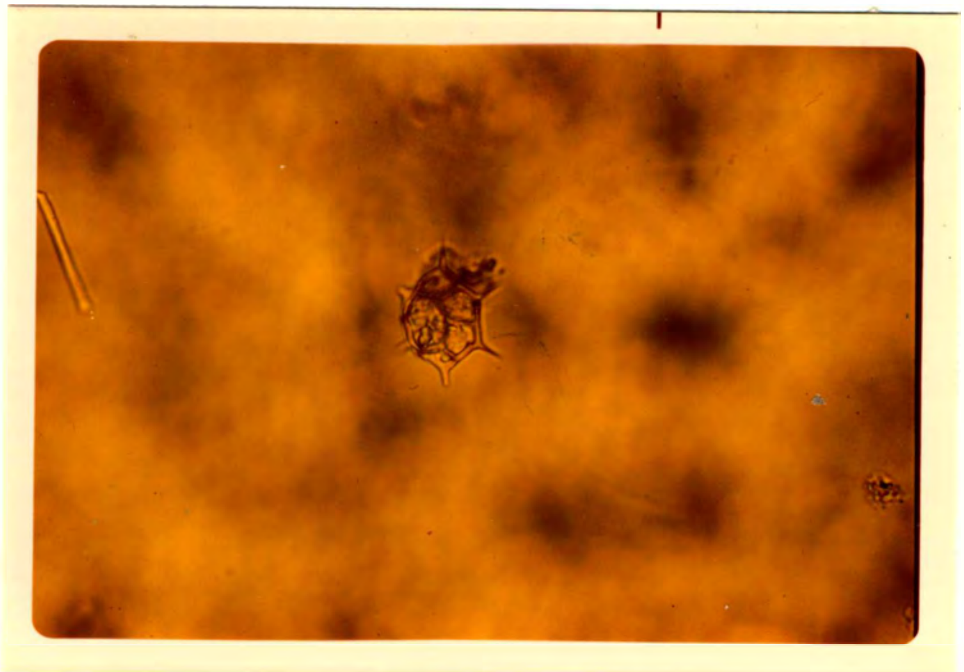


40µ

Rhabdonema minutum Kutzig

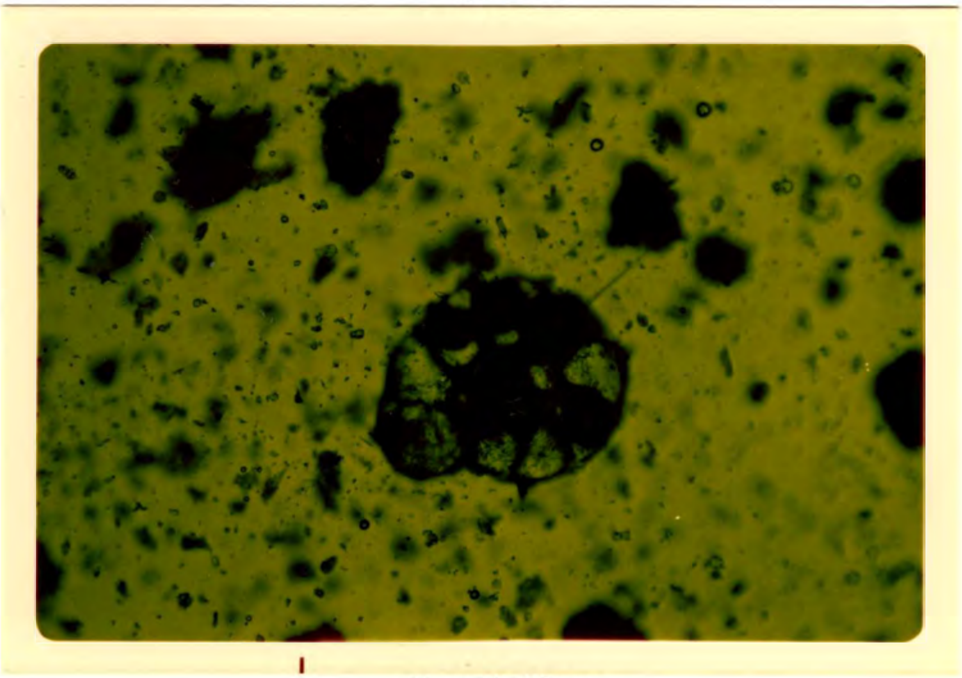
Figure 16

MICROFOSSILS COMMONLY OCCURRING WITH DIATOMS IN EVERSON GLACIOMARINE SEDIMENTS



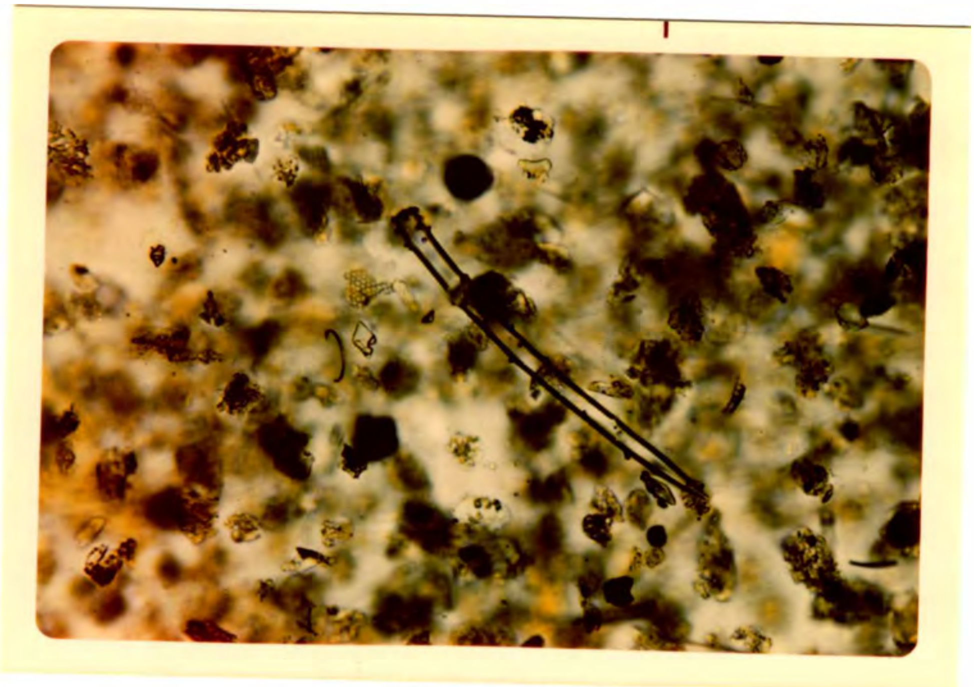
Silicoflagellate

Figure 17

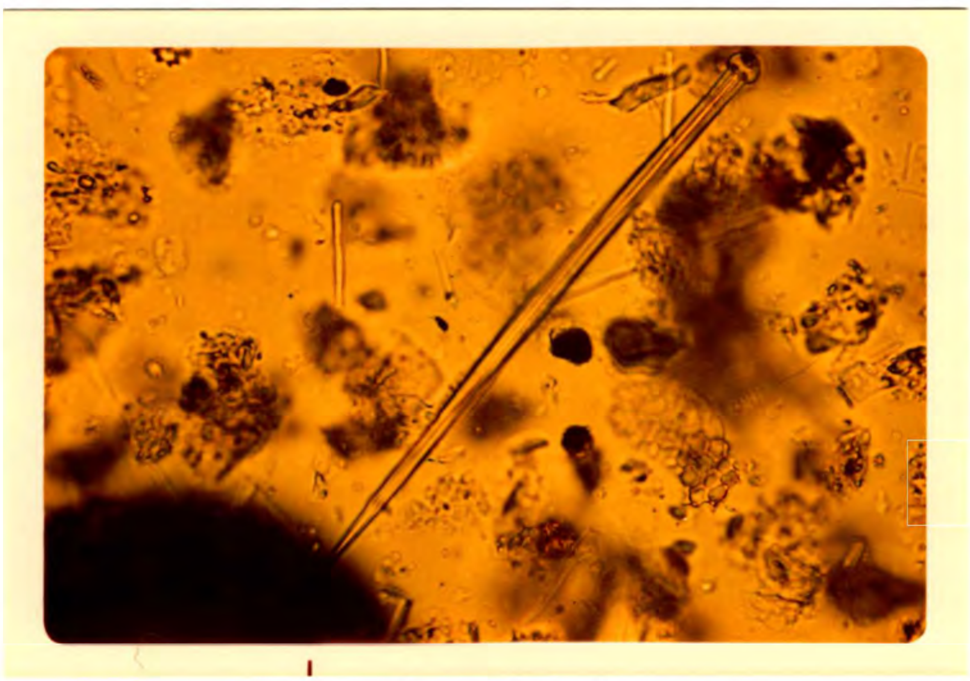


Foraminifera

Figure 18



Sponge Spicule
Figure 19



Sponge Spicule
Figure 20

Lowland, remained relatively constant. The marine waters of the northern Puget Lowland during this time interval contained a uniform flora indicative of sub-arctic waters, and a winter-low isotherm of 5° centigrade. The diatom assemblage associated with the oldest known locality of Everson glaciomarine drift in the northern Puget Lowland, (Penn Cove, Whidbey Island, 13,010 ±170 years B.P.) is dominated by the diatom Campylodiscus thuretii (41%). C. Thuretii is restricted in habitat to littoral zones (Heurck, 1896). The occurrence of photosynthesizing organisms in littoral zones is incompatible with self ice environments. All assemblages reported here show unrestricted communication with the oceanic photic zone, a situation considered unlikely in the presence of an extensive body of self ice.

Previous work by Armstrong and Brown (1954) and Easterbrook (1963, 1966) lead to the conclusion that the bulk of transport of sediment at this time was due to either shelf or berg ice. The results reported here strongly support the contention that if shelf ice did exist in the Puget Lowland, its existence was short lived, as there was no evidence to support its presence at 13,010 ±170 years B.P. in the northern Puget Lowland.

Additional support for this hypothesis came from a study by Miller (1974) of the Gastineau Channel Formation, a composit glaciomarine deposit near Juneau, Alaska. This deposit is correlative in age with Everson glaciomarine deposits (Miller, 1974). Analysis of the geomorphic expression and the stratigraphic position of this formation lead to the conclusion that berg and sea ice were the dominant depositional agents, and that deposition of these units occurred at a time when the area was free of fiord-filling glaciers (Miller, 1974).

Conclusions

Analysis of the Everson glaciomarine sediments has demonstrated: 1) although diatoms are limited in occurrence, they are a valuable tool in recognition of these units; 2) the glaciomarine units are shown to have an easily recognizable and uniform diatom flora; 3) diatoms may be used for paleoenvironmental analysis in areas of high sedimentation; 4) diatoms can be used to demonstrate a glaciomarine origin for lithologically indistinct sections; 5) Puget Lowland marine waters were characterized by a 5° centigrade winter-low isotherm and normal marine salinities during the Everson Interstade; 6) shelf ice was not widely present in the Puget Lowland during the lower Everson Interstade; and 7) berg ice was probably the dominant agent of deposition for Everson glaciomarine drift.

INVESTIGATIONS OF ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

The second technique presented here as a means of distinguishing glaciomarine drift from till is anisotropy of magnetic susceptibility, a rapid, indirect method of estimation of the preferred orientation of inequant grains in a sample (Fuller, 1964).

Degree of elongate grain orientation in undeformed sedimentary rocks has long been recognized as a function of shear in the depositional environment (Krumbien and Sloss, 1963). Anisotropy of magnetic susceptibility is a fully tested indirect method for estimation of fabric due to grain alignment. The technique measures the preferred orientation of a large number of multidomain magnetic minerals, most commonly rod-shaped magnetite. The orientation of these grains (the magnetic fabric) commonly reflects any pervasive petrofabric elements within the rock (Fuller, 1964; Gravenor et al, 1973).

The magnetic fabric has been shown to be independent, to a large degree, of the detrital remanent magnetism present in a specimen. Anisotropy of magnetic susceptibility is measured in an alternating external magnetic field. Detrital remanent magnetization is measured in a constant magnetic field (usually zero). This distinction permits separation of the magnetic effects of remanent and induced magnetization. Multidomain magnetite crystals acquire an induced magnetic moment in low magnetic fields, whereas the smaller grains, which carry the remanent magnetization, for the most part, do not. Thus the torque on a multidomain grain suspended in an alternating field is always in the same direction, whereas the torque on the smaller grains changes with each alternation of the field. This phenomena is diagramatically presented in Figure 21.

The upper size limit of pseudo-single domain magnetite crystals is approximately 17μ in length (Evans and others, 1968). Magnetite of this size or smaller is largely inert to anisotropy of magnetic susceptibility measurements. These grains are responsible for the "hard" detrital remanent magnetization of a sample and do not affect investigations into the magnetic fabric of a sample. Multidomain magnetite crystals up to 180μ in length are affected by the geomagnetic couple (Rees and Woodhall, 1975), in the absence of external shear. Thus, magnetite grains in the size range from 180μ to 17μ are affected by the geomagnetic couple. Data presented here indicated that enough coarse-grained magnetite typically is present in the sampled sediments to justify consideration of their magnetic fabric as primarily a function of shear in the environment of deposition.

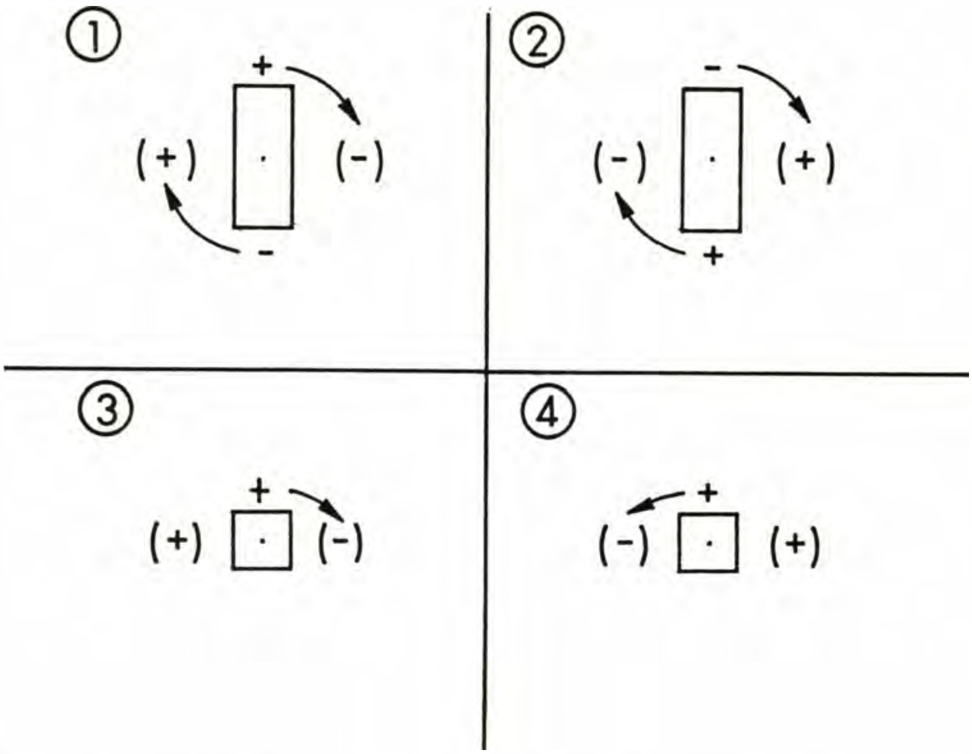


Figure 21. Diagramatic representation of the difference in behavior of multidomain magnetite crystals and single domain magnetite crystals in an alternating external magnetic field.

1. A multidomain crystal is suspended in a magnetic field, and acquires an induced magnetic moment. A magnetic couple is produced, causing a clockwise torque on the crystal.

2. If the polarity of the external field is reversed, the induced moment of the crystal also reverses polarity. The resultant torque is in the same direction as in #1.

3. When a single domain crystal is suspended in an exterior field, a torque results from the magnetic couple.

4. When the external field changes polarity, the moment of the single domain crystal is unaffected. The resultant torque is opposite to #3, and if the oscillation of the field is rapid enough the net effect is zero.

Lodgement till is deposited in a water-saturated, high-shear environment at the base of a glacier (Boulton, 1971) and has been shown to contain a well defined, highly variable magnetic fabric which accurately reflects its petro-fabric (Fuller, 1964; Gravenor and Stupavsky, 1975). Glaciomarine drift consists of clastic particles dropped from floating ice in marine waters, (Armstrong and Brown, 1954; Easterbrook, 1963). The constituent elongate particles of glaciomarine sediments should be more randomly oriented than those of subglacial till as the environment of deposition of the glaciomarine sediments lacks a pervasive element of shear of the magnitude associated with subglacial till. This experiment is a test of the previously noted hypothesis.

The purpose of my work was to determine if the sediments under investigation contain magnetic signatures which can be used to distinguish till from glaciomarine drift.

Sample Collection and Preparation

Three sediment types were analyzed in the experiment: Everson glaciomarine drift, Vashon till, and till from Nebraska (See Figures 22 and 23 for sample localities). Samples of glaciomarine drift and till from Nebraska, which were typically very clay-rich, were collected by driving a nonmagnetic cylinder (a seven dram plastic phial) into freshly exposed sediment. Vashon till was typically too compacted and coarse-grained to be sampled in this manner; samples collected from this unit were hand carved into right cylinders and then mounted in the plastic cylinders. All samples were sealed in paraffin.

Analytical Technique

Samples were measured with a SSM-1A spinner magnetometer using the six spin method of Gravenor and Stupavsky, (1975). Data were reduced using the method of successive approximation (Nye, 1960).

The most practical way to describe the anisotropy of magnetic susceptibility of a specimen is through calculation of a best-fitting second rank tensor or by characterizing the anisotropy of the specimen as an ellipsoid. Extraction of the eigenvectors from the susceptibility tensor can be performed by standard mathematical techniques (Stone, 1963). These eigenvectors should represent the axes of the best fit ellipsoid. However, for tills, the method of fitting an ellipsoid by successive approximation (Nye, 1960) is preferred because, as explained by Gravenor and Stupavsky (1975), "it does not break down for, 1) samples with small magnetic susceptibility anisotropy; and 2) magnetic susceptibility that cannot be adequately represented by an ellipsoid because of experimental measurement errors, or within-specimen inhomogeniety caused by short wave length variation in till fabric."

Two types of fabrics are commonly found in sedimentary rocks (Potter and Pettijhon, 1963). One is a planar fabric or bedding produced by the settling of particles under the influence of gravity; this fabric is most frequently the best developed grain-fabric element present in sediments. The second is linear and is due to the action of forces tangent to the bed. The magnetic fabric most commonly observed in undeformed sediments has elements that have been described as the magnetic foliation and the magnetic lineation (Rees, 1965). The magnetic foliation is parallel to the bedding, and the magnetic lineation lies within the magnetic foliation plane (Rees et al, 1968). The parameter used in this study to estimate the degree of magnetic foliation is Kmax-Kmin/Kint (Kmax, Kint, Kmin are the principle axes of a susceptibility ellipsoid) (Rees, 1965). The parameter used here to estimate the degree of magnetic lineation is Kmax-Kint/Kint; to the author's knowledge this parameter

Figure 22. Anisotropy of magnetic susceptibility sample locations, Nebraska.

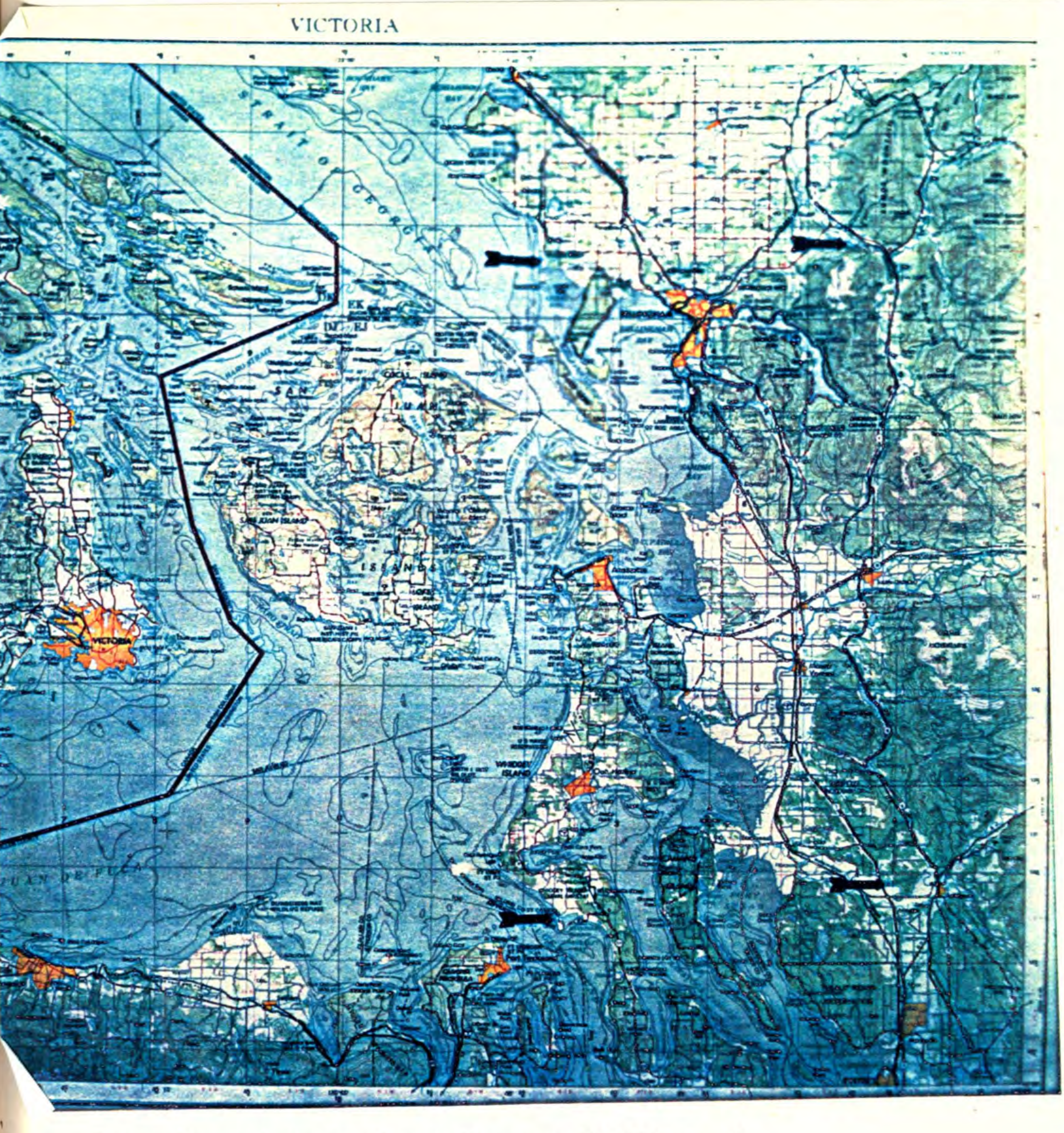


Figure 23. Anisotropy of magnetic susceptibility sample locations, Puget Lowland.

has not previously appeared in the literature. Both of these indices are nearly independent of the bulk susceptibility of the magnetic material and of its concentration in the sediment and so may be used to compare different sediments. Note that for a sphere both of these parameters are zero.

Results and Discussion

Table 5 shows the values of the principle axes for each sample whose anisotropy of magnetic susceptibility could be characterized by an ellipsoid. Table 6 shows the values for the fabric parameters used in the study. Figures 24 and 25 are graphical presentations of the fabric parameters in Table 6. Mean values for each population were compared using a modified students test. Table 7 is a tabulation of this comparison.

Table 5

Principle axes of ellipsoids of susceptibility.

Till from Nebraska

Sample #	Min.	Int.	Max.
3301	.1553 E-02	.2121 E-02	.2137 E-02
3302	.1471 E-02	.2110 E-02	.2238 E-02
3304	.1768 E-03	.8012 E-03	.8032 E-03
3305	.1381 E-02	.1968 E-02	.2011 E-02
3306	.1256 E-02	.1767 E-02	.1880 E-02
3307	.4869 E-03	.6406 E-03	.9187 E-03
3308	.1742 E-02	.1998 E-02	.2162 E-02
3310	.2686 E-03	.5880 E-03	.6050 E-03
3311	.1873 E-02	.2256 E-02	.2403 E-02
3313	.1146 E-03	.5333 E-03	.5896 E-03
3314	.1627 E-02	.2103 E-02	.2123 E-02
3315	.2095 E-03	.5740 E-03	.6767 E-03
3316	.3817 E-03	.7914 E-03	.8691 E-03
3317	.8748 E-03	.1395 E-02	.1447 E-02
3318	.1439 E-02	.1853 E-02	.1911 E-02
3320	.2950 E-03	.3486 E-03	.7702 E-03
3322	.9864 E-03	.1424 E-02	.1488 E-02
3325	.1356 E-02	.1857 E-02	.1927 E-02
3327	.1307 E-02	.1989 E-02	.2026 E-02
3329	.1706 E-02	.2453 E-02	.2656 E-02
3330	.1149 E-02	.1702 E-02	.1804 E-02
3331	.1971 E-02	.2566 E-02	.2733 E-02

3333	.1820 E-02	.2428 E-02	.2497 E-02
3335	.8826 E-04	.7849 E-03	.8971 E-03
3336	.1594 E-02	.2082 E-02	.2170 E-02
3337	.5982 E-04	.4824 E-03	.6404 E-03
3338	.2679 E-03	.7445 E-03	.7950 E-03

Vashon Till

Sample #	Min.	Int.	Max.
2203	.3017 E-02	.3741 E-02	.4434 E-02
2204	.3658 E-02	.4320 E-02	.4602 E-02
2209	.5388 E-02	.6059 E-02	.6697 E-02
2210	.4859 E-03	.1053 E-02	.1456 E-02
2211	.2915 E-02	.3418 E-02	.3804 E-02
2212	.1476 E-02	.2106 E-02	.2341 E-02
2215	.1167 E-01	.1242 E-01	.1271 E-01
2216	.5268 E-02	.6151 E-02	.6202 E-02
2218	.1323 E-02	.1912 E-02	.2177 E-02
2219	.2740 E-02	.2879 E-02	.3400 E-02
2222	.5640 E-02	.5937 E-02	.6517 E-02
2225	.1561 E-02	.1981 E-02	.2123 E-02
2226	.2859 E-03	.1296 E-02	.1318 E-02
2227	.3171 E-02	.3931 E-02	.4220 E-02
2228	.2375 E-02	.2736 E-02	.3279 E-02
2229	.1355 E-02	.2107 E-02	.2395 E-02
2230	.1486 E-02	.1938 E-02	.2245 E-02
2231	.5467 E-02	.6072 E-02	.6446 E-02
2232	.4295 E-02	.4782 E-02	.4940 E-02

2233	.1356 E-02	.1808 E-02	.1921 E-02
2235	.2686 E-02	.3324 E-02	.3422 E-02
2240	.3820 E-02	.3986 E-02	.4463 E-02
2241	.3708 E-02	.3861 E-02	.4577 E-02
2242	.2443 E-02	.2806 E-02	.3026 E-02
2247	.7516 E-02	.8118 E-02	.8125 E-02

Glaciomarine Drift

Sample #	Min.	Int.	Max.
1113	.4084 E-02	.4211 E-02	.4416 E-02
1114	.2215 E-02	.8122 E-02	.8863 E-02
1115	.8536 E-02	.9142 E-02	.9225 E-02
1116	.6941 E-02	.7628 E-02	.7903 E-02
1119	.4033 E-02	.4288 E-02	.4604 E-02
1124	.3412 E-02	.3895 E-02	.4228 E-02
1126	.4438 E-02	.4987 E-02	.4003 E-02
1129	.3509 E-02	.4003 E-02	.3109 E-02
1130	.2636 E-02	.2986 E-02	.3109 E-02
1134	.3564 E-02	.3928 E-02	.4161 E-02
1135	.3209 E-02	.3734 E-02	.4011 E-02
1137	.3486 E-03	.9820 E-03	.1005 E-02
1138	.2039 E-02	.2594 E-02	.2872 E-02
1139	.4466 E-03	.1001 E-02	.1043 E-02
1141	.2685 E-02	.2972 E-02	.3117 E-02
1148	.4463 E-02	.4660 E-02	.4925 E-02
1149	.2720 E-02	.2888 E-02	.3183 E-02
1150	.3603 E-02	.3918 E-02	.4393 E-02

1151	.1150 E-02	.1712 E-02	.1788 E-02
1152	.1283 E-02	.1941 E-02	.1982 E-02
1154	.2377 E-02	.2908 E-02	.3225 E-02
1158	.3590 E-02	.3900 E-02	.4085 E-02

Table 6

Numerical values for fabric parameters

Till from Nebraska

Sample #	(Kmax-Kmin)/Kint.	(Kmax-Kint)/Kint.
3301	.2753	.0075
3302	.3635	.0607
3304	.7818	.0025
3305	.3201	.0220
3306	.3531	.0640
3307	.6741	.4341
3308	.2102	.0821
3310	.5721	.0289
3311	.2349	.0652
3313	.8907	.1056
3314	.2359	.0095
3315	.8139	.1789
3316	.6159	.0982
3317	.4102	.0373
3318	.2547	.0313
3320	1.3630	1.2094
3322	.3522	.0449
3325	.3368	.0377

3327	.3615	.0186
3329	.3873	.0828
3330	.3850	.0599
3331	.2970	.0651
3333	.2790	.0264
3335	1.0301	.1429
3336	.2767	.0423
3337	1.2041	.3275
3338	.6872	.0678
	mean = .5169	mean = .1242
	variance = .0990	variance = .0563

Vashon Till

Sample #	(Kmax-Kmin)/Kint	(Kmax-Kint)/Kint
2203	.3788	.1852
2204	.2185	.0653
2209	.2160	.1053
2210	.9213	.3827
2211	.2601	.1129
2212	.4107	.1115
2215	.0837	.0225
2216	.1518	.0083
2218	.4467	.1385
2219	.2292	.1809
2222	.1477	.0977
2225	.2837	.0717
2226	.7964	.0170

2227	.2669	.0735
2228	.3304	.1985
2229	.4936	.1367
2230	.3916	.1584
2231	.1612	.0616
2232	.1349	.0330
2233	.3125	.0625
2235	.2214	.0295
2240	.1613	.1129
2241	.2251	.1854
2242	.2078	.0784
2247	.0750	.0009
	mean = .3010	mean = .1050
	variance = .0388	variance = .0068

Glaciomarine Drift

Sample #	(Kmax-Kmin)/Kint	(Kmax-Kint)/Kint
1113	.0788	.0487
1114	.1413	.0912
1115	.0754	.0091
1116	.1261	.0361
1119	.1332	.0737
1124	.2095	.0855
1126	.1134	.0297
1129	.1381	.1191
1130	.1584	.0412
1134	.1520	.0593

1135	.1248	.0742
1137	.6684	.0234
1138	.3211	.1071
1139	.5958	.0420
1141	.1454	.0488
1148	.0991	.0569
1149	.1603	.1021
1150	.2016	.1212
1151	.3727	.0444
1152	.3601	.0211
1154	.2916	.1090
1158	.1269	.0474
	mean = .2179	mean = .0632
	variance = .0254	variance = .0011

Table 7

Test of significance means using a modified students test.

$$\text{compute } t = \frac{\bar{x} - \bar{y}}{sp\sqrt{\frac{(n_1 + n_2)}{(n_1 + n_2)}}}$$

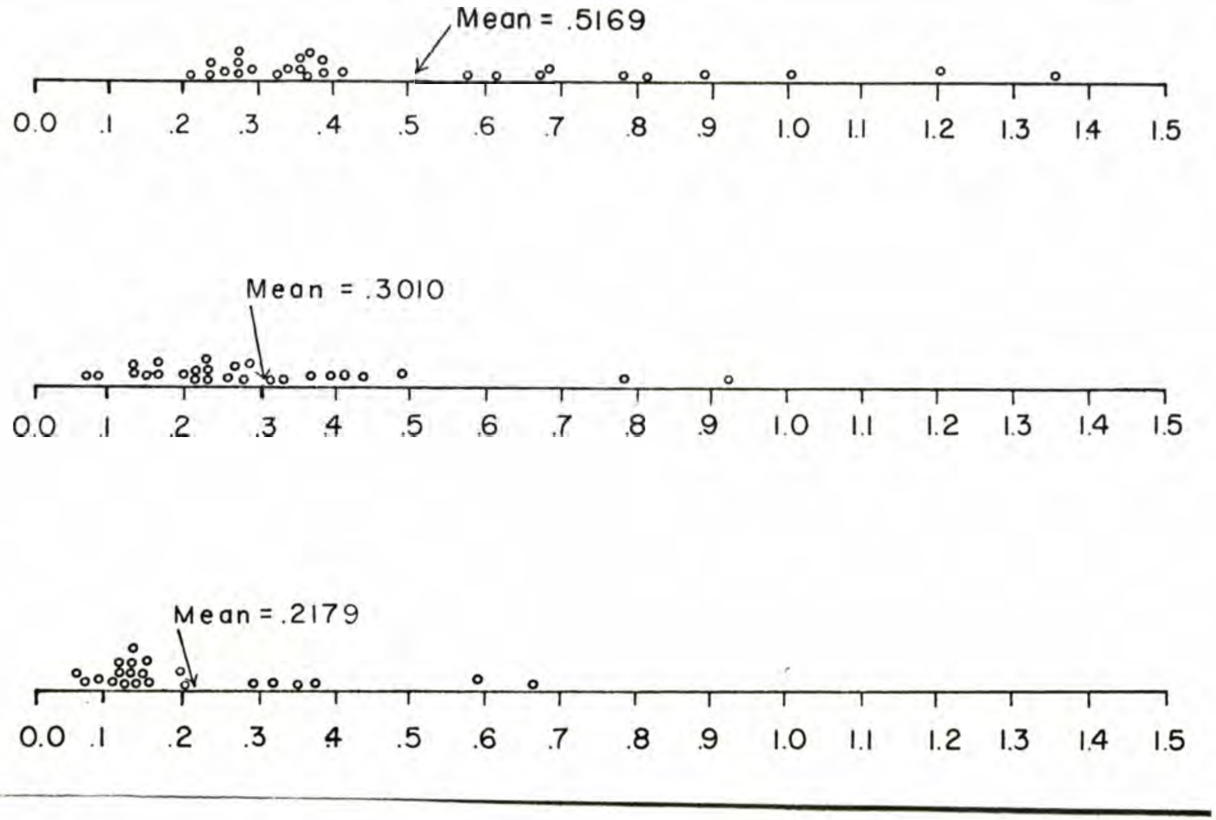
$$\text{where } sp = \frac{(n_1 - 1)\, s_1{}^2 + (n_2 - 1)\, S_2{}^2}{n_1 + n_2 - 2}$$

and $\bar{x}$, $\bar{y}$ = population means, n_1, n_2 = number of observations per population $s_1{}^2$, $s_2{}^2$ = estimated population variances. To test if $\bar{x} = \bar{y}$: where the computed t value exceeds the expected value, $\bar{x} \neq \bar{y}$

(Max-Min)/Int computed t value	Populations test statistic - 99.5% level of confidence
Glaciomarine drift vs. Vashon till 9.12	$t_{(47)}99.5 = 2.576$ ∴ means are significantly different
Glaciomarine drift vs. Till from Nebraska 15.74	$t_{(49)}99.5 = 2.576$ ∴ means are significantly different
Till from Nebraska vs. Vashon till 10.8	$t_{(52)}99.5 = 2.576$ ∴ means are significantly different

(Max-Int)/Int computed t value	Populations test statistic - 99.5% level of confidence
Glaciomarine drift vs. Vashon till 38.0	$t_{(47)}99.5 - 2.576$ ∴ means are significantly different
Till from Nebraska vs. Glaciomarine drift 6.54	$t_{(49)}99.5 - 2.576$ ∴ means are significantly different
Vashon till vs. Till from Nebraska 2.11	$t_{(52)}99.5 = 2.576$ ∴ means are not significantly different for this level of confidence

(Kmax-Kmin)/Kint



Till from Nebraska

mean = .5169

variance = .0990

Vashon Till

mean = .3010

variance = .0388

Everson Glaciomarine Drift

mean = .2174

variance = .0254

Figure 24. Graphical presentation of values for (Kmax-Kmin)/Kint magnetic fabric parameter.

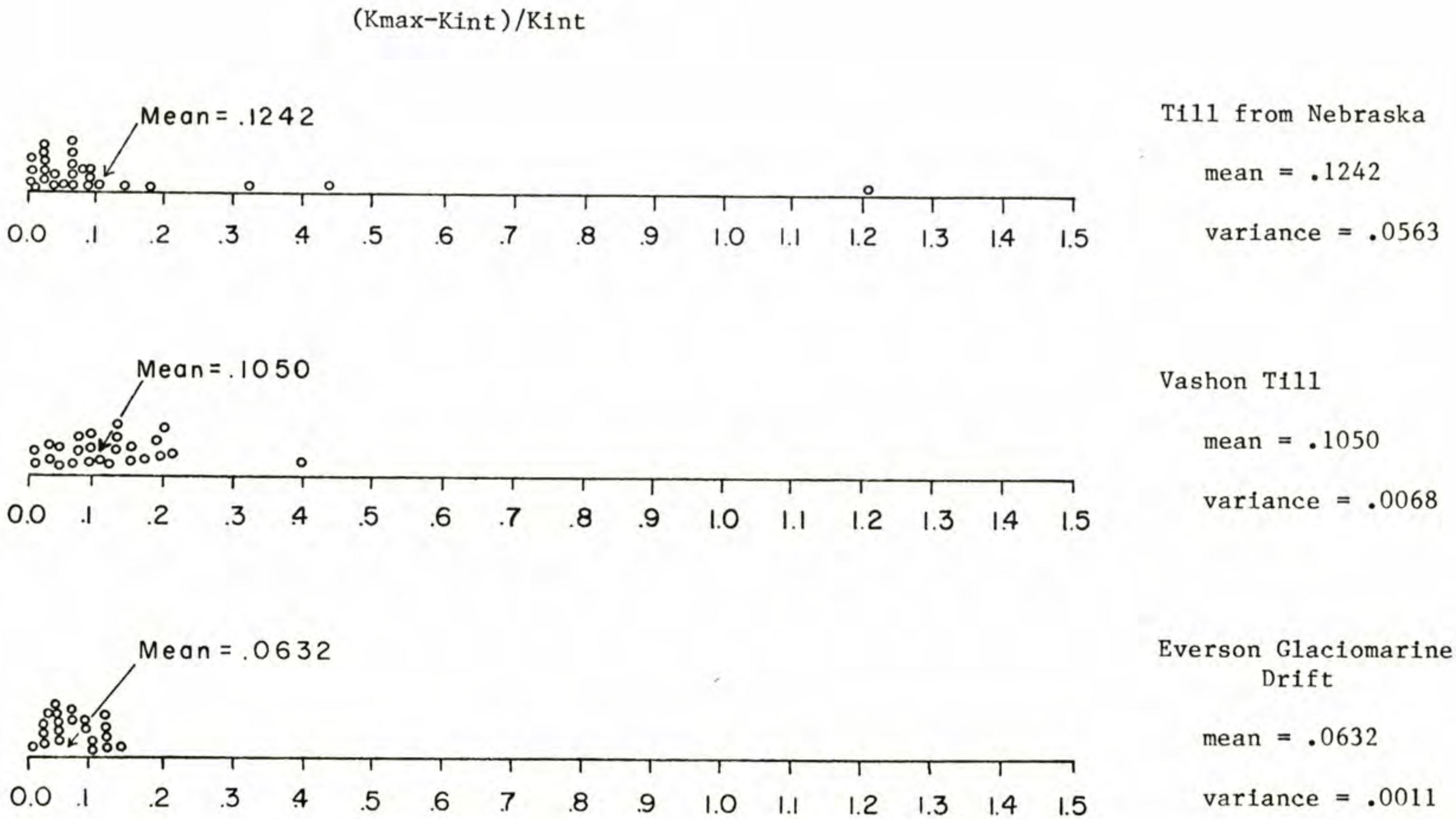


Figure 25. Graphical presentation of values for (Kmax-Kint)/Kint magnetic fabric parameter.

The results of this comparison concur with the hypothetical model, (see page 32). The ellipsoid of susceptibility of glaciomarine drift tends significantly toward a more spherical shape than either of the tills.

A tendency for glaciomarine sediments to have a relatively poorly defined plane of magnetic foliation relative to till is clearly documented. This observation is in accord with the typically massive nature of glaciomarine sediments. The lack of bedding in glaciomarine sediments indicates that both the non-magnetic and magnetic components of the sediment are not constrained by the dynamics of this depositional environment to preferentially come to rest in nearly horizontal orientations.

The lack of a pervasive element of shear in the marine environment is here thought to be responsible for the poorly developed magnetic lineation in glaciomarine drift relative to till. The relationship of shear in the depositional environment to degree of magnetic lineation in a sediment is direct, as discussed by Rees and Woodhall (1975).

The ellipsoid of susceptibility of a sediment is dependent upon grain size, mineralogy, and conditions controlling the amount of shear in the environment of deposition. (Rahman, et al, 1975; Rees and Woodhall, 1975). The intra-till comparisons reflect variations in these parameters in significantly different values of magnetic foliation between the tills. Divergence in this fabric element may be due to: 1) the pore pressure at the glacier base may have been higher in one instance than the other; 2) frozen ground may have existed under one glacier and not under the other; 3) dissimilar particle size distributions may exist in the two diamictons; 4) there may be differences in mineralogy due to separate provenances; 5) differences may have existed in the flow velocities of the two glaciers. The values of magnetic lineation, however, are not significantly different.

Because factors controlling the magnetic signature of a sediment are complex and difficult to isolate, differences in magnetic signature in themselves are not adequate to distinguish between subglacial tills with differing provenances.

Conclusions

A characteristic magnetic signature has been defined for the two sediment types examined. Glaciomarine sediments are shown to contain a significantly more random magnetic fabric than subglacial till. Glaciomarine ellipsoids of susceptibility are significantly more spherical than those characteristic of till. Anisotropy of magnetic susceptibility is useful in distinguishing glaciomarine drift from two subglacial tills of widely divergent sedimentary regimes.

REFERENCES CITED

Abbott, W.H., 1972, Micropaleontology and paleoecology of Miocene non-marine diatoms from the Harper district, Malheur County, Oregon: M.S. Thesis, Northeast Louisiana Univ., Monroe, 103p.

Armstrong, J.E., 1960, Surficial geology of the Sumas map area, British Columbia: Geol. Surv. Canada, Paper 59-9, 27p.

Armstrong, J.E. and Brown, W.L., 1954, Late Wisconsin marine drift and associated sediments of the Lower Fraser Valley, British Columbia, Canada: Geol. Soc. America Bull., vol. 65, p.349-364.

Barron, J.A., 1973, Late Miocene-Early Pliocene paleotemperatures for California from marine diatom evidence: Paleogeography, Paleoclimatology, Paleoecology, vol. 14, p.277-291.

Boulton, G.S., 1971, Till genesis and fabric in Svalbard, Spitsbergen: in Goldthwaith, R.P. (ed.), Till: A Symposium, Ohio State Univ. Press, Columbus, p.41-72.

Brady, H.T., 1977, Late Neogene diatom biostratigraphy and paleoecology of the Dry Valleys and McMurdo Sound, Antarctica: M.S. Thesis, Northern Illinois Univ., De Kalb, 143p.

Cupp, E.E., 1943, Marine plankton diatoms of the west coast of North America: Univ. of California Press, Berkeley, 221p.

Easterbrook, D.J., 1963, Late Pleistocene glacial events and relative sea level changes in the northern Puget Lowland, Washington: Geol. Soc. America Bull., vol. 74, p.1465-1484.

Easterbrook, D.J., 1964, Void ratios and bulk densities as means of identifying Pleistocene tills: Geol. Soc. America Bull., vol. 75, p.745-750.

Easterbrook, D.J., 1966, Glaciomarine environments and the Fraser Glaciation in northwest Washington: Guidebook for the first annual field conference, Pacific Coast section of Friends of the Pleistocene, Bellingham, 52p.

Evans, M.E., McElhinny, M.W. and Gifford, A.C., 1968, single domain magnetite and high coercivities in a gabbroic intrusion: Earth and Planetary Sci. Letters, vol. 4, p.142-146.

Flint, R.F., 1957, Glacial and Pleistocene geology: John Wiley and Sons, New York, New York, 553p.

Fuller, M.D., 1964, A magnetic fabric in till: Geol. Mag., vol. 99, p.233-237.

Gran, H.H. and Angst, E.C., 1931, Plankton diatoms of Puget Sound: Publications of the Puget Sound Biological Station, vol. 7, Univ. of Washington Press, Seattle, p.417-519.

Gravenor, C.P., Stupavsky, M., Symon, D.T., 1973, Paleomagnetism and its relationship to till deposition: Canadian Jour. Earth Sci., vol. 10, p.1068-1078.

Gravenor, C.P., and Stupavsky, M., 1975, Convention for reporting magnetic anisotropy of till: Canadian Jour. Earth Sci., vol. 12, p.1063-1069.

Heath, R.G., 1974, Dissolved silica and deep-sea sediments: In Hay W.W. (ed.), Studies in Paleooceanography: Soc. of Economic Paleontologists and Mineralogists Special Publication No. 20, p.150-173.

Heurck, H.V., 1896, A treatise on the Diatomaceae; William Wesley and Son, London, 558p.

Jouse, A.P., 1971, Diatoms in Pleistocene sediments from the northern Pacific Ocean: in Funnel, B.M. and Riedel, W.R. (ed.), Micropaleontology of the Oceans, Cambridge Univ. Press, Cambridge, p.151-159.

Jouse, A.P., Kozlova, O.G. and Muhina, V.V., 1971, Distribution of diatoms in the surface layer of sediment from the Pacific Ocean: in Funnel, B.M. and Riedel, W.R. (ed.), Micropaleontology of the Oceans, Cambridge Univ. Press, Cambridge, p.263-271.

Jouse, A.P., Kozlova, O.G. and Muhina, V.V., 1969, Diatoma i siliko-flagellaty sloe osadkov Tikhogo Okeana. In U.G. Kort (ed.), Tikhii Okean: Mikroflora i Mikrofauna v Souremenngkh Osadrakh Tikhogo Okeana. Nauka, Moscow, p.7-47.

Krebs, W.N., 1977, Ecology and preservation of neritic marine diatoms, Arthur Harbor, Antarctica: Ph.D. Thesis, Univ. of California, Davis, 203p.

Krumbein, W.C. and Sloss, L.L., 1963, Stratigraphy and sedimentation: W.H. Freeman, San Francisco, 497p.

Lisitin, A.P., 1969, Recent sedimentation in the Bering Sea: Israel program for Scientific Translations Press, Jerusalem, 614p.

Lisitin, A.P., 1971, Distribution of siliceous microfossils in suspension and in bottom sediments: in Funnel, B.M. and Riedel, W.R. (ed.), Micropaleontology of the Oceans, Cambridge Univ. Press, Cambridge, p.171-173.

Mallory, V.S., 1972, Paleoecology of the Kulshan Glaciomarine Drift, Bellingham Bay, Washington: 45th Ann. Meeting Northwest Scientific Association. Western Washington State College, Abstracts of papers, Bellingham, p.9.

Miller, R.D., 1974, Gastineau Channel Formation, a composite glaciomarine deposit near Juneau, Alaska: U.S. Geol. Survey Bull., No. 1394-C, 20p.

Nye, J.F., 1960, Physical properties of crystals: Clarendon Press, Oxford, 322p.

Patrick, R. and Reimer, C.W., 1966, The diatoms of the United States exclusive of Alaska and Hawaii, vol. I: Monographs of the Academy of Natural Sciences of Philadelphia, 688p.

Potter, P.E. and Pettijohn, F.J., 1963, Paleocurrents and basin analysis, Springer, Berlin-Gottingen-Heidelberg, 295p.

Rahman, A.U., Gough, D.I. and Evans, M.E., 1975, Anisotropy of magnetic susceptibility of the Martin Formation, Saskatchewan, and its sedimentological implications: Canadian Jour. Earth Sci., vol. 12, p.1465-1473.

Rees, A.I., 1965, The use of anisotropy of magnetic susceptibility in the estimation of sedimentary fabric: Sedimentology, vol. 4, p.257-271.

Rees, A.I., Von Rod, U. and Shepard, F.P., 1968, Magnetic fabric of sediments from the La Jolla submarine canyon and fan, California: Marine Geology, vol. 6, p.145-178.

Rees, A.I. and Woodhall, W.A., 1975, The magnetic fabric of some laboratory deposited sediments: Earth and Planetary Sci. Letters, vol. 25, p.121-130.

Smith, R.K., 1970, Late glacial foraminifera from southeast Alaska and British Columbia and world wide high northern latitude, shallow water faunal province: Archives Des Sciences, vol. 23, p.675-701.

Schrader, J.H., 1971, Fecal pellets, role in sedimentation of pelagic diatoms: Science, vol. 174, No. 4004, p.55-57.

Schrader, J.H., 1974, Proposal for a standardized method of cleaning diatom-bearing deep-sea and land-exposed marine sediments: in Simonsen, R., (ed.), Recent and fossil marine diatoms, Nova Hedwigia, Beih, No. 45, p.403-409.

Stone, D.B., 1963, Anisotropic magnetic susceptibility measurements on a phonolite and on a folded metamorphic rock: Royal Astron. Soc., Geophysical Jour., vol. 7, p.375-390.

HOLOCENE GEOGRAPHICAL DISTRIBUTION OF DIATOMS IN THE NORTH PACIFIC

APPENDIX I

Fossil diatom investigations of sediment in the Pacific Ocean have lead to the delineation of distinct ecological groups which are indicative of surface water temperatures. The geographical distribution of these ecological groups has been shown to shift rapidly in response to changes in surface water temperatures throughout the late Pleistocene, (Jouse, 1971).

The Holocene geographical distribution of these ecological groups is shown in Figure 1, (Jouse, Kozlova and Muhina, 1969).

A brief description of each group and its ecological significance follows taken from Jouse, Kozlova and Muhina,(1971, p.267.)

I. The Arctoboreal diatom complex as observed in the sediments, is characterized by the presence of the following species: *Thalassiosira nordenskioldii* Cl., *T. gravida* Cl., *Bacterosira fragilis* Gran, *Chaetoceros furcellatus* Bail., *Biddulphia aurita* Breb. et Godey. The Arctoboreal diatom complex is typical of sediments of the continental and insular shoals of the Okhotsk and Bering seas and also for the ocean's northern margins. Its southern most occurrence is opposite to Hokkaido. This complex includes the neritic-glacial diatom flora which vegetates in spring during ice thawing and beneath ice following the melting of the ice cover. Diatoms of the complex are distinguished by their maximum cold-loving characteristics, superseding that of other plankton species in the ocean's northern areas.

II. The North boreal diatom complex features the following species: *Thalassiosira excentrica* Cl., *Th. gravida* Cl., *Coscinodiscus curcatulus* Gran., *C. marginatus* Ehr., *C. oculus-iridus* Ehr., *Actinocyclus divisus* Gran., *Bacterosira fragilis* Gran., *Denticula semina* Simonsen and Kanaya, *Rhabdonema arcuatum* Gran., and *Rhizosolenia hebetata* Gran.

The area of mass occurrence of North boreal diatoms in sediments coincides with the area of distribution of subarctic waters. In a number of stations the content of North boreal species encountered in the complex composition reaches 90-94 percent; they develop mainly in the plankton of the open ocean.

In the near-Kamchatka and near-Kuril area, as well as next to the coasts of North America, the North boreal complex is mixed with neritic Archtoboreal species. Thalassiosira gravida Cl., Biddulphia aurita Breb. et Godey and Melosira sulcata (Ehr.) Kutz. The southern boundary of the area marked by profuse occurrence of North boreal species coincides with the northern boundary of the Polar Front. In the northwestern margins of the ocean it extends to 38° N, but near the coast of North America it rises to 54° N. In the northwest of the ocean this boundary is shifted to the south under the influence of the cold Oyashio current. At the junction point of the cold Oyashio and the warm Kuroshio currents intense mixing of waters occurs, both in the vertical and horizontal directions, and this increases the diatom content of sediments. The mixed water forms a Polar Front, a transitory zone about 2° to 4° wide. The zone is precisely reflected in the sediments. The content of North boreal species is reduced to 50 percent. Near the coast of North America, where all isotherms rise to the north compared with the western marginal areas, the participation of warm-loving species in the diatom complex is especially striking.

III. The Subtropical diatom complex of sediments is formed by the following species: Thalassiosira decipiens Jor., T. lineata Jouse, Coscinodiscus radiatus Ehr., Thalassionema nitzschioides Gran. (a complexus of forms), Pseudoeunotia doliolus (Wall.) Gran., Roperia tesselata (Roper) Gran., Nitzschia bicapitata Cl., N. interrupta Heid., N. sicula (Castr.) Hust, etc. The greater proportion of these species occurs in the sediments of the open ocean.

The northern boundary of the zone marked by a high occurrence of subtropical species appears to be coincident with the southern boundary of the zone for the distribution of the North boreal complex. Amongst the greater number of stations south of 40° - 45° N a predominance of moderately warm-loving diatom subtropical species (55-60 percent of the total number) has been noticed. The mass concentration of these species in sediments suggests that these latitudes are the areal center for many species of the complex. This situation naturally leads to a question; what species are the remaining 30-45 percent of sediments south of 40° - 45° N made up of? Our investigations show that the northern boundaries of the diatom belt reveal North boreal species, which infrequently comprise 30-40 percent. In the south, next to the zone of subtropical convergence, the complex composition is built up of subtropical species 62 percent, North boreal species 5.3 percent, tropical species 26.3 percent, and sublittoral benthic species 1.9 percent.

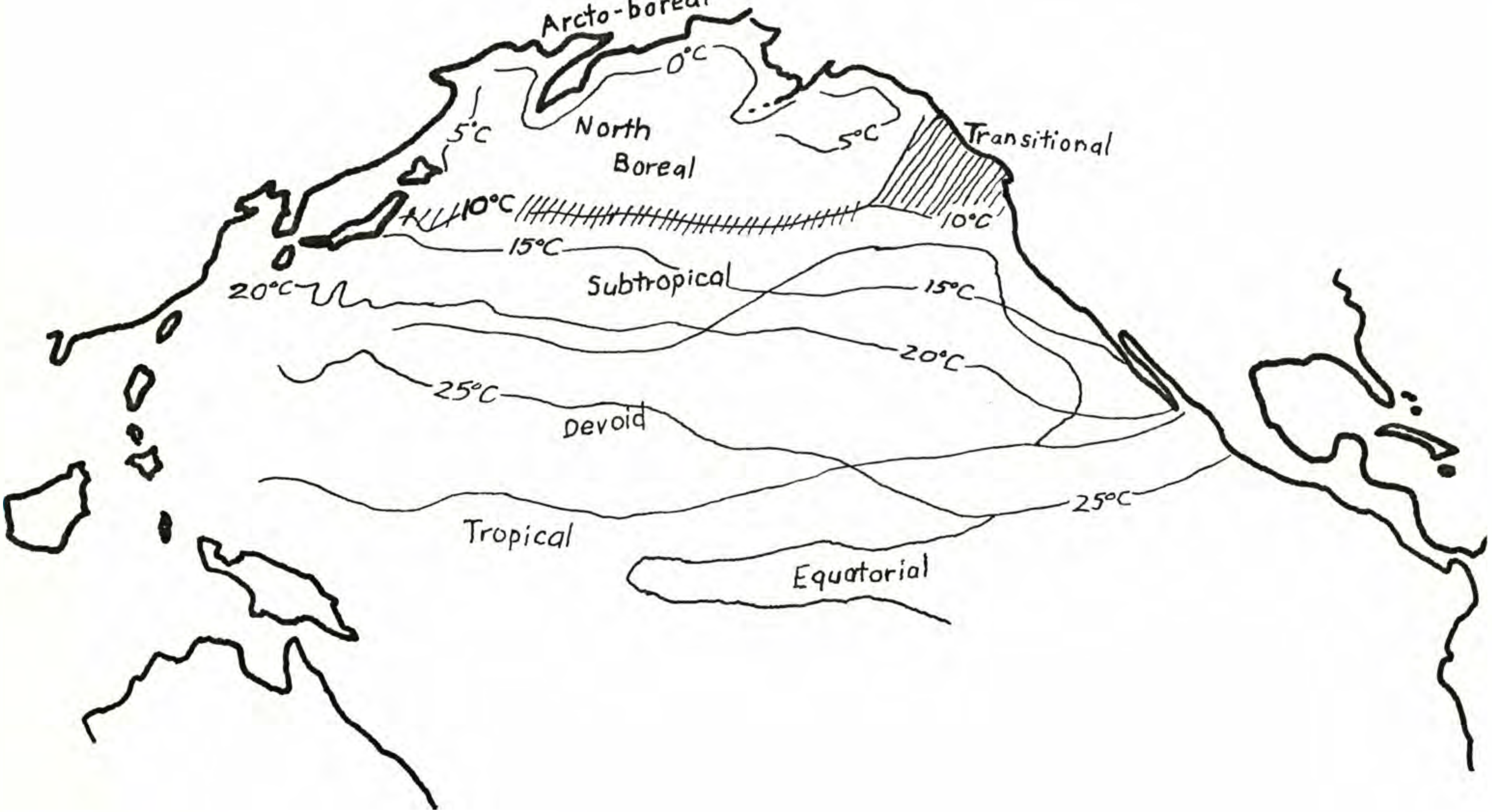


Figure 26. Holocene geographic distribution of diatoms in the northern Pacific. (Jouse et al., 1969).

APPENDIX II

FLORAL REFERENCE LIST

Biddulphia auria (Lyngbye), Cupp, 1943; Gran and Angst, 1931; Heurck, 1896, p.471, pl. 20, p.631.

Biddulphia roperiana Greville, Gran and Angst, 1931, p.500, Fig. 78.

Campylodiscus thuretii Breb, Heurck, 1896, p.378, pl. 14, Fig. 595.

Coscinodiscus curvatulus Grunow, Cupp, 1943; Gran and Angst, 1931; Jouse, 1971, p.416, Fig. 5-6.

Coscinodiscus marginatus Ehrenberg, Cupp, 1943; Gran and Angst, 1931, Heurck, 1896, p.527.

Coscinodiscus Occulus-iridus Ehrenberg, Cupp, 1943; Gran and Angst, 1931; Jouse, 1971, p.416, Fig. 14.

Melrosira sp Agarth, Gran and Angst, 1931; Heurck, 1896, p.236.

Navicula distans W. Smith, Cupp, 1943; Gran and Angst, 1931; Heurck, 1896, p.185, pl. 3, Fig. 133.

Nitzchia seriata Cleve, Gran and Angst, 1931, p.503, Fig. 44.

Rhabdonema arcuatum Grunow, Jouse, 1971; Heurck, 1896, p.360, pl. 12, Fig. 487 a.

Rhabdonema minutum Kutzig, Heurck, 1896, p.361, pl. 12, Fig. 488 a.

Rhabdonema sp. Kutzing, Heurck, 1896, p.360.

Suriella sp. Turpin, Heurck, 1896, p.368.

Thalassiosira decipiens (Grunow), Cupp, 1943; Gran and Angst, 1931, p.450, Fig. 3.

Thalassiosira excentrica Cleve, Gran and Angst, 1931; Jouse, 1971, p.416, Fig. 1.

Thalassiosira sp. Cleve, Cupp, 1943; Gran and Angst, 1931; Heurck, 1896, p.436.

Thalassiothrix longissima Cleve and Grunow, Cupp, 1943; Gran and Angst 1931; Heurck, 1896, p.322.

APPENDIX III

SAMPLE LOCALITIES

Everson Glaciomarine Drift Diatom Localities

Bayview Ridge
Everson glaciomarine drift exposed in road side ditch.
T35N, R3E, N.W. 1/4, N. 1/2, sec. 33.

Bayview Ridge borrow pit
Everson glaciomarine drift, youngest diamicton exposed in the pit.
T35N, R3E, N.W. 1/4, N. 1/2, sec. 21.

Governor's Point
Everson glaciomarine drift exposed in a road side ditch.
T37N, R3E, S.W. 1/4, S. 1/2, sec. 25.

East Wing, Wilson Library, Western Washington Univ.
Everson glaciomarine drift exposed in foundation excavation.
T38N, R3E, S.W. 1/4, S. 1/2, sec. 31.

Bellingham Bay
Kulshan glaciomarine drift exposed in sea cliffs adjacent to cement plant.
T37N, R2E, N.W. 1/4, N. 1/2, sec. 25.

Bellingham Bay
Bellingham glaciomarine drift exposed in sea cliffs adjacent to Cliffside, Washington. T37N, R3E, S.E. 1/4, S. 1/2, sec. 23.

Kiket Island
Everson glaciomarine drift exposed on beach cut, northeast side of the island. T33N, R3E, N.E. 1/4, N. 1/2, sec. 21.

Swantown, Whidbey Island
Everson glaciomarine drift exposed in sea cliffs. T32N, R1E, S.W. 1/4, S. 1/2, sec. 5.

Partridge Point, Whidbey Island
Everson glaciomarine drift exposed in sea cliffs. T32N, R1E, S.W. 1/4, N. 1/2, sec. 6.

Penn Cove, Whidbey Island
Everson glaciomarine drift exposed in sea cliffs. T32N, R1E, S.W. 1/4, N. 1/2, sec. 6.

Cedarville
Bellingham glaciomarine drift exposed in cliffs along the Nooksack River.
T39N, R4E, 1/4, N. 1/2, sec. 34.

Nooksack River
Bellingham glaciomarine drift exposed in cliffs along the Nooksack River.
T 39N, R 4E,1/4, N.E. 1/4, N.W. 1/4, N. 1/2, sec. 35.

Orcas Island
Everson glaciomarine drift exposed in road side ditch.
T 37N, R 2W, N.E. 1/4, N. 1/2, sec. 22.

Fraser Lowland, [(49° 01' 25" N; 122° 45' 50")]
Everson glaciomarine drift exposed in a road side ditch on King George Highway (99A) 4km north of the U.S. border.

MAGNETIC FABRIC SAMPLE LOCALITIES

1) Neptune Beach, Washington.
Vashon till exposed in sea cliffs. T38N, R3E, S.E. 1/4, N. 1/2, sec. 16.

2) Cedarville, Washington.
Bellingham glaciomarine drift exposed in cliffs along the Nooksack River. T38N, R4E, N.E. 1/4, S. 1/2, sec. 34.

3) Stillaguamish River, Washington.
Vashon till exposed in I-5 road cut at the intersection of I-5 and the Stillaguamish River. T31N, R5E, S.W. 1/4, N. 1/2, sec. 32.

4) Fort Casey, Washington.
Vashon till exposed in sea cliffs. T32N, R1E, S.W. 1/4, S. 1/2, sec. 11.

5) David City, Nebraska.
Till from a drill core, see Figure 6.

6) Twin Bluffs,
Till from a drill core, see Figure 6.

COMPUTER PROGRAMS FOR CALCULATING MAGNETIC FABRIC PARAMETERS

PROGRAM #1

```
   DIMENSION NAME(20)
   MAGNETIC SUSCEPTIBILITY ANISOTROPY CALCULATION

   PRINCIPAL SUSCEPTIBILITIES BY METHOD OF SUCCESSIVE APPROXIMATIONS

   SUSC MATRIX USED IS NON SYMMETRIC K12,K13,K23 ARE NOT EQUAL TO K21
   ,K31,K32 RESPECTIVELY
   IF SYMMETRIC MATRIX WANTED MUST MAKE K12=K21,K13=K31,K23=K32

1 FORMAT('0',118HCORENUMBER   DEC1    INC1    MAGNITUDE1    DEC2    INC2
 1   MAGNITUDE2    DEC3    INC3     MAGNITUDE3 MAX/INT   MIN/INT NMAX NMIN
 2 )
2 FORMAT('0',30X,26HPRINCIPAL SUSCEPTIBILITIES)
3 FORMAT(' ',A4,A2,A2,A2,1X,1F5.1,2X,1F5.1,3X,1E10.4,2X,1F5.1,2X,1F5
 1.1,3X,1E10.4,2X,1F5.1,2X,1F5.1,3X,1E10.4,1X,1F7.4,1X,1F7.4,2X,1I4,
 22X,1I4)
5 FORMAT(     A4,A2,A2,A2,9F6.3,F6.2)
7 FORMAT(' ',15X,59HMINIMUM                          INTERMEDIATE
 1      MAXIMUM)

   STACK CARDS AS FOLLOWS

   'NAME CARD' COL2-40. (ALPHANUMERIC)
   'N CARD' COL 1-3. GIVES NUMBER OF SPECIMENS FOR WHICH THE 'CORE CA
   RD IS VALID.
   'CORE CARD' COL1-8 CORE IDENTIFICATION
   COL 9-15 CORE DECLINATION
   COL 16-23 CORE INCLINATION
   COL 23-30 MULTIPLIER ON SSM-1A
   N 'SPECIMEN CARDS'
   COL 1-10 SPECIMEN I.D.
   COL11-16 K12
   COL 17-22 K21
   COL 23-28 K11-K22
   COL 29-34 K31
   COL 35-40 K13
   COL 41-46 K33-K11
   COL 47-52 K23
   COL 53-58 K32
   COL 59-64 K33-K22
   COL 65-70 K22
   NEXT CARD IS 'N CARD'
   NEXT CARD IS 'CORE CARD'
   AND SO ON
   TERMINATE WITH A BLANK CARD

   IF K22 CANNOT BE MEASURED: PUT K22=10.0*MAXIMUM(ABS(D12,D31,D32))

206 FORMAT(A4,A2,A2,2F7.2,F10.7)
204 FORMAT('0',20A2)
210 FORMAT(I2)
700 FORMAT(A4,A2,A2,A2,2F7.2,2E11.4)
   READ204,NAME
   PRINT204,NAME
   PRINT2
   PRINT7
   PRINT1
```

```
      LIBRARY SUBROUTINES USED IN PROGRAM
      SQRT,SIN,COS,ATAN2


      MEANING OF QUANTITIES IN OUTPUT

      NMAX GIVES NUMBER OF ITERATIONS REQUIRED TO COMPUTE  MAX SUSC DIR
      NMIN GIVES NUMBER OF ITERATIONS REQUIRED TO COMPUTE  MIN SUSC DIR
      IF NMAX,NMIN IS EQUAL TO 9000 MAX,MIN SUSC UNSUCCESSFULLY COMPUTED
      BECAUSE MAG SUSC OF SPECIMEN IS INSUFFICIENTLY ANISOTROPIC

      IF MAX/INT IS LESS THAN 1.0 AMS INCORRECTLY COMPUTED
      IF MIN/INT IS GREATER THAN 1.0 AMS IS INCORRECTLY COMPUTED
      BECAUSE MS OF SPECIMEN IS INSUFFICIENTLY ANISOTROPIC
      S13=K13, S31=K31, D31=K33-K11, S22=K22=BULK SUSCEPTIBILITY OF SPEC
      PI=57.296
  406 READ210,N
 4061 IF(N)455,455,407
  407 READ206,CCLN,SITE,CORE,CDEC,CINC,SENS
  408 DO 453 I=1,N
      S12=K12, S21=K21, D12=K11-K22, S23=K23, S32=K32, D32=K33-K22
      READ5,COL2,SIT2,COR2,SPEC,S12,S21,D12,S31,S13,D31,S23,S32,D32,S22
      S11=S22+0.5*(D12+D32-D31)
      S33=S22+0.5*(D31+D12+D32)
      S23=-S23
      S32=-S32
      S13=-S13
      S31=-S31
      INVERSE OF SUSC MATRIX
      DET=S11*(S22*S33-S23*S32)-S12*(S21*S33-S23*S31)+S13*(S21*S32-S31*S
     122)
      A11=(S22*S33-S23*S32)/DET
      A21=(S31*S23-S21*S33)/DET
      A31=(S21*S32-S22*S31)/DET
      A12=(S13*S32-S12*S33)/DET
      A22=(S11*S33-S13*S31)/DET
      A32=(S12*S31-S11*S32)/DET
      A13=(S12*S23-S13*S22)/DET
      A23=(S13*S21-S11*S23)/DET
      A33=(S11*S22-S12*S21)/DET
      CALCULATION OF THE THE MINIMUM SUSCEPTIBILITY DIRECTION
      AA0=0.5756
      BB0=0.5756
      CC0=0.5756
      ITN=0
   10 AA=A11*AA0+A12*BB0+A13*CC0
      BB=A21*AA0+A22*BB0+A23*CC0
      CC=A31*AA0+A32*BB0+A33*CC0
      DD1=1.0/SQRT(AA*AA+BB*BB+CC*CC)
      AA=AA*DD1
      BB=BB*DD1
      CC=CC*DD1
      IF(ABS((AA0-AA)/AA)+ABS((BB0-BB)/BB)+ABS((CC0-CC)/CC)-0.000001)11,
     112,12
   12 ITN=ITN+1
      IF(ITN-9000)13,11,11
   13 AAC=AA
```

```
      BBO=BB
      CCO=CC
      GO TO 10
C     CALCULATION OF THE MAXIMUM SUSCEPTIBILITY DIRECTION
   11 AO=0.5756
      BO=0.5756
      CO=0.5756
      MM=ITN
      ITNN=0
   14 A=S11*AO+S12*BO+S13*CO
      B=S21*AO+S22*BO+S23*CO
      C=S31*AO+S32*BO+S33*CO
      D1=1.0/SQRT(A*A+B*B+C*C)
      A=A*D1
      B=B*D1
      C=C*D1
      IF(ABS((AO-A)/A)+ABS((BO-B)/B)+ABS((CO-C)/C)-0.000001)15,16,16
   16 ITNN=ITNN+1
      IF(ITNN-9000)17,15,15
   17 AO=A
      BO=B
      CO=C
      GO TO 14
   15 NN=ITNN
C     CALCULATION OF THE MAGNITUDE OF MAXIMUM SUSCEPTIBILITY
      QQ=SQRT(A*A+B*B+C*C)
      A=A/QQ
      B=B/QQ
      C=C/QQ
      B11=S11*A+S12*B+S13*C
      B12=S21*A+S22*B+S23*C
      B13=S31*A+S32*B+S33*C
      B1=SENS*SQRT(B11*B11+B12*B12+B13*B13)
C     CALCULATION OF THE MAGNITUDE OF THE MINIMUM SUSCEPTIBILITY
      DDD=SQRT(AA*AA+BB*BB+CC*CC)
      AA=AA/DDD
      BB=BB/DDD
      CC=CC/DDD
      B31=S11*AA+S12*BB+S13*CC
      B32=S21*AA+S22*BB+S23*CC
      B33=S31*AA+S32*BB+S33*CC
      B3=SENS*SQRT(B31*B31+B32*B32+B33*B33)
C     CALCULATION OF THE MAGNITUDE OF INTRMEDIATE SUSCEPTIBILITY
      XX=B*CC-C*BB
      YY=C*AA-A*CC
      ZZ=A*BB-B*AA
      DD=SQRT(XX*XX+YY*YY+ZZ*ZZ)
      XX=XX/DD
      YY=YY/DD
      ZZ=ZZ/DD
      B21=S11*XX+S12*YY+S13*ZZ
      B22=S21*XX+S22*YY+S23*ZZ
      B23=S31*XX+S32*YY+S33*ZZ
      B2=SENS*SQRT(B21*B21+B22*B22+B23*B23)
      R31=B1/B2
      R21=B3/B2
C     CORRECTION FOR DIP AND STRIKE OF CORE
      CIN=CINC/P1
```

```
      RAA=AA*COS(CIN)+CC*SIN(CIN)
      RCC=CC*COS(CIN)-AA*SIN(CIN)
      DDD=SQRT(RAA*RAA+BB*BB+RCC*RCC)
      X3=CDEC-90.0+P1*ATAN2(BB,RAA)
      IF(X3)51,53,55
   51 X3=360.0+X3
   52 GO TO 56
   53 X3=0.0
   54 GO TO 56
   55 X3=X3
   56 IF(X3-360.0)106,107,108
  106 X3=X3
      GO TO 57
  107 X3=0.0
      GO TO 57
  108 X3=X3-360.0
   57 Y3=P1*ARSIN(RCC/DDD)
      RA=A*COS(CIN)+C*SIN(CIN)
      RC=C*COS(CIN)-A*SIN(CIN)
      QQ=SQRT(RA*RA+B*B+RC*RC)
      X1=CDEC-90.0+P1*ATAN2(B,RA)
      IF(X1)61,63,65
   61 X1=360.0+X1
   62 GO TO 66
   63 X1=0.0
   64 GO TO 66
   65 X1=X1
   66 IF(X1-360.0)103,104,105
  103 X1=X1
      GO TO 67
  104 X1=0.0
      GO TO 67
  105 X1=X1-360.0
   67 Y1=P1*ARSIN(RC/QQ)
      XXX=XX*COS(CIN)+ZZ*SIN(CIN)
      ZZZ=ZZ*COS(CIN)-XX*SIN(CIN)
      DD=SQRT(XXX*XXX+YY*YY+ZZZ*ZZZ)
      X2=CDEC-90.0+P1*ATAN2(YY,XXX)
      IF(X2)71,73,75
   71 X2=360.0+X2
   72 GO TO 76
   73 X2=0.0
   74 GO TO 76
   75 X2=X2
   76 IF(X2-360.0)100,101,102
  100 X2=X2
      GO TO 77
  101 X2=0.0
      GO TO 77
  102 X2=X2-360.0
   77 Y2=P1*ARSIN(ZZZ/DD)
      PRINT3,COL2,SIT2,COR2,SPEC,X3,Y3,B3,X2,Y2,B2,X1,Y1,B1,R31,R21,NN,M
     1M
      S22=S22*SENS
      PUNCH700,COL2,SIT2,COR2,SPEC,X1,Y1,B1,S22
      PUNCH700,COL2,SIT2,COR2,SPEC,X3,Y3,B3,S22
      PUNCH700,COL2,SIT2,COR2,SPEC,X2,Y2,B2,S22
  453 CONTINUE
```

```
  454 GO TO 406                                                          00002330
  455 CALL EXIT                                                          00002340
      STOP                                                               00002350
      END                                                                00002360
```

PROGRAM #2

```
      C   DEPT GEOLOGY,
          DIMENSION NAME(20)
          DIMENSION H1(99),H2(99),H3(99),H4(99),H5(99),H6(99),DD4(99)
          DIMENSION X(99),Y(99),Z(99),DD5(99),DD6(99)
          DIMENSION AA(3,99),BB(3,99),C(3,99),DD(99),DD1(99),DD2(99),DD3(99
      501 FORMAT(' ',A4,A2,A2,A2,23X,F7.4,2X,E10.3,2X,E10.3,2X,F7.4,2X,F7.4
         12X,F7.4)
      516 FORMAT('0',33H*****MEAN FABRIC PARAMETERS*****,F7.4,2X,E10.3,2X,
         110.3,2X,F7.4,2X,F7.4,2X,F7.4,9H MEAN MS=,E11.4)
      517 FORMAT(' ',33H**STAND. DEV. FABRIC PARAMETERS**,F7.4,2X,E10.3,2X,
         110.3,2X,F7.4,2X,F7.4,2X,F7.4,11H ST DEV MS=,E11.4)
      500 FORMAT('0',92HCORENUMBER FABRIC PARAMATERS (MAX-MIN)/INT  MAX-INT
         1.5*(MAX+INT)-MIN    Q    MAX/INT   MIN/INT)
      365 FORMAT('0',34H****STANDARD DEVIATIONS*****DEC=,F7.2,1X,3HDEG,2X
         14HINC=,F7.2,1X,3HDEG)
      366 FORMAT(' ',34H95 PER CENT CONFIDENCE LIMITS DEC=,F7.2,1X,3HDEG,2X
         14HINC=,F7.2,1X,3HDEG)
      203 FORMAT('0',20A2)
        1 FORMAT(A4,A2,A2,A2,2F7.2,2E11.4)
      206 FORMAT('0',60HCORE NUM N     DECL    INCL   INTENSITY     R         K
         1        A95)
      207 FORMAT(' ',A4,A2,A2,I2,2X,2F7.2,E10.3,F9.5,F8.2,F7.2)
     2071 FORMAT('0',36HCORENUMBER     DECL    INCL   INTENSITY)
      205 FORMAT(' ',A4,A2,A2,A2,2X,2F7.2,E11.4)
      211 FORMAT(I2)
       14 FORMAT('0')
      300 READ 203,NAME
      304 PRINT203,NAME
          PI=57.296
        2 READ211,N
          IF(N)2,2,4
        4 DO5K=1,N
          READ1,DD(K),DD1(K),DD2(K),DD3(K),AA(1,K),BB(1,K),C(1,K),DD4(K)
          READ1,DD(K),DD1(K),DD2(K),DD3(K),AA(2,K),BB(2,K),C(2,K),DD4(K)
          READ1,DD(K),DD1(K),DD2(K),DD3(K),AA(3,K),BB(3,K),C(3,K),DD4(K)
        5 CONTINUE
          RN=N
          DO515J=1,3
          PRINT2071
          S1=0.0
          S2=0.0
          S3=0.0
          S4=0.0
          S5=0.0
          S6=0.0
          S7=0.0
          SS1=0.0
          SS2=0.0
          SS3=0.0
          SS4=0.0
          SS5=0.0
          SS6=0.0
          SS7=0.0
          SX=0.0
          SY=0.0
          SZ=0.0
          ST=0.0
      310 DO 360 I=1,N
```

```
      RDEC=AA(J,I)
      RINC=BB(J,I)
      RINT=C(J,I)
      DD5(I)=RDEC
      DD6(I)=RINC
      PRINT205,DD(I),DD1(I),DD2(I),DD3(I),RDEC,RINC,RINT
      H1(I)=(C(3,I)-C(1,I))/C(2,I)
      H2(I)=C(3,I)-C(2,I)
      H3(I)=0.5*(C(3,I)+C(2,I))-C(1,I)
      H4(I)=H2(I)/H3(I)
      H5(I)=C(3,I)/C(2,I)
      H6(I)=C(1,I)/C(2,I)
      S1=S1+H1(I)
      S2=S2+H2(I)
      S3=S3+H3(I)
      S4=S4+H4(I)
      S5=S5+H5(I)
      S6=S6+H6(I)
      S7=S7+DD4(I)
      SS1=SS1+H1(I)*H1(I)
      SS2=SS2+H2(I)*H2(I)
      SS3=SS3+H3(I)*H3(I)
      SS4=SS4+H4(I)*H4(I)
      SS5=SS5+H5(I)*H5(I)
      SS6=SS6+H6(I)*H6(I)
      SS7=SS7+DD4(I)*DD4(I)
      X(I)=COS(RDEC/PI)*COS(RINC/PI)
      Y(I)=SIN(RDEC/PI)*COS(RINC/PI)
      Z(I)=SIN(RINC/PI)
      SY=SY+Y(I)
      SX=SX+X(I)
      SZ=SZ+Z(I)
      ST=ST+RINT
  360 CONTINUE
      AVINT=ST/RN
      RM=SQRT(SX*SX+SY*SY+SZ*SZ)
      CRDEC=PI*ATAN2(SY,SX)
      IF(CRDEC)361,363,362
  361 CRDEC=360.0+CRDEC
      GO TO 363
  362 IF(CRDEC-360.0)363,363,364
  364 CRDEC=CRDEC-360.0
  363 CRINC=PI*ARSIN(SZ/RM)
      ACOC=ABS(1.0-((RN-RM)/RM)*((20.0)**(1.0/(RN-1.0))-1.0))
      IF(ACOC-1.0)479,479,478
  478 ACOC=90.00
      GO TO 482
  479 ACOC=PI*ARCOS(ACOC)
  482 PPK=(RN-1.0)/(RN-RM)
      PRINT206
      PRINT207,DD(N),DD1(N),DD2(N),N,CRDEC,CRINC,AVINT,RM,PPK,ACOC
      SDEC=0.0
      SINC=0.0
      DO510I=1,N
      DEC=ABS(CRDEC-DD5(I))
      IF(DEC-180.0)311,311,312
  312 DEC=360.0-DEC
  311 SDEC=SDEC+DEC*DEC
```

```
          SINC=SINC+(CRINC-DD6(I))*(CRINC-DD6(I))
      510 CONTINUE
          SDEC=SQRT(SDEC/(RN-1.0))
          SINC=SQRT(SINC/(RN-1.0))
          SRDEC=1.96*SDEC/SQRT(RN)
          SRINC=1.96*SINC/SQRT(RN)
          PRINT365,SDEC,SINC
          PRINT366,SRDEC,SRINC
      515 CONTINUE
          PRINT500
          DO 502I=1,N
          PRINT501,DD(I),DD1(I),DD2(I),DD3(I),H1(I),H2(I),H3(I),H4(I),H
         1H6(I)
      502 CONTINUE
          P=N
          R=P-1.0
          R=1.0/R
          B=1.0/P
          A1=S1*R
          A2=S2*R
          A3=S3*R
          A4=S4*R
          A5=S5*R
          A6=S6*R
          A7=S7*R
          PRINT14
          PRINT516,A1,A2,A3,A4,A5,A6,A7
          D1=SQRT(B*(SS1-S1*S1*R))
          D2=SQRT(B*(SS2-S2*S2*R))
          D3=SQRT(B*(SS3-S3*S3*R))
          D4=SQRT(B*(SS4-S4*S4*R))
          D5=SQRT(B*(SS5-S5*S5*R))
          D6=SQRT(B*(SS6-S6*S6*R))
          D7=SQRT(B*(SS7-S7*S7*R))
          PRINT517,D1,D2,D3,D4,D5,D6,D7
          GO TO 2
        3 STOP
          END
```